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ORIGINAL ARTICLES.

The Geological Work of the Cambridge Expedition to the East African Lakes, 1930–31.

By V. E. Fuchs, M.A.

(Continued from p. 112.)

B. THE WESTERN RIFT VALLEY.

I. General.

At its southern end the western rift valley branches westwards from the trend of the main rift valley at a point just north of Lake Nyasa. Thence it continues northwards for a distance of approximately 1,000 miles, when it ends in the Sudan near Nimule.

Like the eastern rift it contains a chain of lakes, but in general these differ from those on the east in being a deeper type of lake. Here also there have been two periods of rift valley formation, both of which were accompanied by volcanic activity. After each phase of faulting there was a period of great precipitation followed by one of increasing aridity.

The volcanic activity was slight compared to that of the eastern rift and, as might be expected, this milder form of vulcanicity permitted the existence of faunas which are now found fossil in the Pleistocene deposits of the region.

The following deals with the Pleistocene of the Lake Edward and Lake George basins.

II. The Lake Edward Basin.

During the early Pleistocene a large sheet of water lay over the sites of the present Lake Edward and Lake George basins, and this lake was probably in direct connection with Lake Albert. A now extinct fauna lived in and around the lake and is preserved in the

Pleistocene deposits left by it. These beds are of the same age as the Kaiso Series of Lake Albert, so named from the village of Kaiso where they were first described.[1] It seems that during their deposition

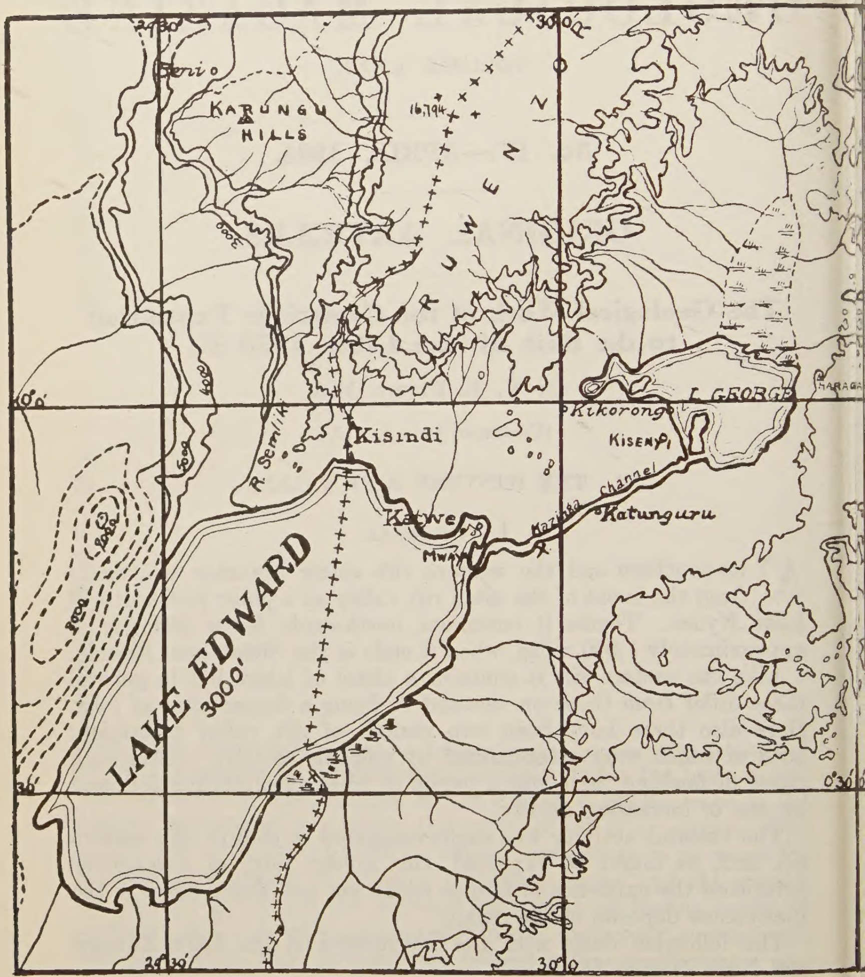

Fig. 6.

the climate became more and more arid, for towards the top of the series are gypsiferous clays and deposits of "kunkar",[2] together with frequent but discontinuous ironstone bands which are sometimes oolitic. It is in these ironstone horizons that most of the fossils are found. The reason for this concentration is that as the lake retreated and broke up into shallow pools, the fauna was crowded in and about them and gradually died out completely.

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[1] E. J. Wayland.

[2] "Kunkar," small limestone concretions of irregular shape that occur disseminated throughout clays or sands, or may form a separate deposit.

The Kaiso fauna from the Lake Edward deposits includes the following :—

MAMMALS.
Phacochoerus sp.
Hippopotamus cf. *imaguncula.*

REPTILES.
Crocodilus niloticus.
Trionyx sp.

FISH.
Lates sp. probably *niloticus.*
Synodontis sp.

MOLLUSCA.
Viviparus dubius (Cox).
,, *unicolor* (Martens).
,, *turris* (Cox).
,, *alberti* (Cox).
Cleopatra (cf.) *ferruginea* (Lea).
,, *bifidicincta* (Cox).
Potadoma ganahli (Connolly).
Mutela ?
Unio parreysia (Cox).
Pliodon (Conrad).

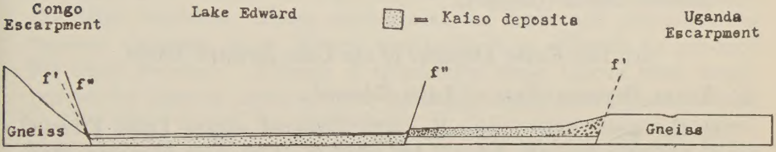

FIG. 7.

The drying-up of the Kaiso Lake may be correlated with that of the lake or lakes of the Kamasian period in the eastern rift. Here, too, as in the eastern rift, renewed faulting took place approximately at the time of maximum aridity. In the Lake Edward Basin, the faulting on the east took a new line at some distance from, but parallel to, the original Miocene fault, whereas on the west of the lake it took the form of further movement along the old fault, as far north as the source of the Semliki. At this point it was apparently diverted to the east by the massif of the Bukuku Hills, at whose foot the Kaiso beds are heavily faulted.

Sounding in Lake Edward shows that its floor is tilted towards the west, thereby indicating that the throw of the mid-Pleistocene faulting on the west is greater than that on the east.

Subsequent to these movements precipitation again began to increase. A lake appeared in the shallow new basin formed by the beginnings of subsidence. To this new lake there came a fauna completely different from that found in the Kaiso deposits. It exists there to-day, and though some of its members are apparently locally extinct, it is typical of the fauna found in the Nile basin. It includes :—

MAMMALS.

A few teeth and small fragments of hippopotamus ; also a few antelope remains.

REPTILES.

None found. It seems that the crocodiles and turtles have never found their way back to the lake during the Second Pluvial Period.

FISH.

All the fish found in the lake to-day are allied to Nile types, and it is noticeable that the Nile perch, *Lates niloticus* and *Synodontis* do not live in the lake to-day, though they did so during the First Pluvial. No fossil fish belonging to the Gamblian were found.

MOLLUSCA.

Viviparus rubicunda.
Melanoides tuberculata (Müller).
,, ,, ,, slender race.
Cleopatra pirothi (Jickelli).
Planorbis adowensis (Bourguignat).
Coelotura egyptiaca (Cailliaud).
Unio teretiusculus (Philippi).
Corbicula africana (Krauss).
Corbicula consobrina (Cailliaud).
Aetheria elliptica (Lamarck).

(*a*) *The Kaiso Deposits of the Lake Edward Basin.*

(i) *Kaiso Deposits East of Lake Edward.*

At the point where the Kazinga Channel enters Lake Edward on the north-east, the lake is bounded by a steep overgrown shore forming high cliffs. The cliffs are formed of sands and sandy clays in which occur a considerable amount of kunkar. No good exposures were found till Kateta was reached, where, along the shore of the lake, the cliffs become more pronounced. Owing to the great number of small fault blocks that have been formed, it is difficult to make out any old lake levels. There is, however, one more or less persistent level between 35 and 40 feet above the lake, which will later be referred to in connection with the reversal of the Semliki River. The cliffs on the shore just north of Kateta are composed of brown and yellow clays with occasional lenses of sand and gravel. Twelve feet from the base of the cliff there is a constant 6-in. band of fine, grey ash, indicating that there was already volcanic activity in this area long before the close of the First Pluvial.

South of Kateta, beside a papyrus swamp, there is a low cliff at the base of which occurs a thin ironstone band which yielded numerous casts and impressions of mollusca. These are of Kaiso age and are the only fossils found south of Kayenga headland on the east of the lake.

As already stated, the lake shore rises in a series of steps due to the small fault blocks. The flat tops of these are covered with a thin layer of gravel and kunkar nodules, together, in some cases, with numerous pebbles of ironstone. The latter appear to have been derived from a kunkar band, containing small ironstone nodules, that occurs about 10 feet below the top of the deposits. The possible occurrence of ironstones further to the east is indicated by a few scattered boulders of unfossiliferous carstone that lie on the surface of the plain formed by the lake beds.

(ii) *Kaiso Deposits North of Lake Edward.*

North of the Mwaya isthmus are seen the first ashes that are of any importance in the series. From there fine tuffs form the uppermost deposits as far round the lake as the Semliki River.[1] As Wayland has pointed out the walls of the crater are formed of beds dipping outwards, indicating that they are not composed of material ejected from Katwe itself, but have been bent from their normal horizontal position by the explosion that formed that crater. Surrounding the crater and on its inner slopes there are fragments of gneisses and lavas that have been torn from the side of the pipe. On the slope towards the lake near Katwe Rest Camp a number of blocks of ironstone crowded with gastropods were found strewn amongst the other boulders. These are certainly of Kaiso age and since the nearest exposure is at Mwaya peninsula it is difficult to account for their presence. Though it is possible these blocks were transported by human agency, it is unlikely that, having been carried so far, they would be jettisoned. If they were not so carried, then they can only have reached the present position through being thrown out from Katwe crater. This would indicate the occurrence of fossiliferous Kaiso beds below the tuffs.

Kaiso deposits are seen in the Lubelia gorge north of old Kasindi on the Congo-Uganda boundary. The section there exposed consists of clays, sands, and coarse gravels, through which are dispersed large quantities of kunkar. In all, the depth of beds exposed is approximately 60 feet, of which the uppermost 6 feet are water-laid ashes.

East of the Lubelia and about ½ mile south of Katojo there is a level area ending abruptly to the south where the ground slopes steeply away towards the low-lying country near the lake, and across which the Lubelia has cut its channel. The surface of this plateau lies at about 110 feet above the lake. The top layers are composed of 2 feet of micaceous ash lying upon 8 feet of coarse gravel which contains many fragments of pegmatite, presumably derived from the slopes of Ruwenzori, a few miles to the north. Below this is a coarse sandstone containing angular fragments of felspar and quartz cemented by a calcareous matrix.

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[1] E. J. Wayland, *Summary of Progress of the Geological Survey of Uganda*, 1919–20, p. 17.

The steep front that bounds this flat to the south seems to indicate the line of a fault which cut through the Kaiso Lake beds. Here too, the ashes may be seen to have been deposited subsequent to the faulting, since where they have not later been removed by erosion they can be seen to lie undisturbed by it.

(iii) *Kaiso Deposits West of Lake Edward.*

On the west of the lake, Kaiso deposits were found at the source of the Semliki where the river has cut a deep section through them. No ironstone bands can be seen in the cliffs by the river, these being composed of sands and clays with lenses of gravel. Owing to the precipitousness of the cliffs and the swiftness of the river, it was impossible to approach this section closely, except at two points, one, where the river flows out of the lake, and the other at the bend in the river where it finally turns northwards.

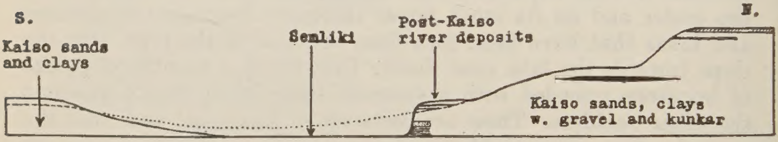
S.
N.
Kaiso sands and clays
Semliki
Post-Kaiso river deposits
Kaiso sands, clays w. gravel and kunkar

FIG. 8.

Fig. 8 shows a section across the source of the river. On the north bank there is a cliff about 35 feet high, of which the lower 25 feet are of Kaiso clays and sands, the upper 10 feet being river deposits of post-Kaiso age. The lowest Kaiso bed exposed is a gypsiferous clay, which indicates that dry conditions had already set in. In the upper part of the deposits of the Kaiso Series seen here, two bands of ironstone occur at 50 and 100 feet above the lake. Neither of these is more than 6 inches thick, and both are quite unfossiliferous. The Kaiso beds are overlain by 3 feet of dark, micaceous ash, apparently of Gamblian date.

That this succession is fairly constant is seen from a section about 2 miles to the north-west, where the river turns northwards. There, also, there are two ironstone horizons which are slightly fossiliferous, yielding a few fossils typical of the Kaiso.

A few fragments of bone were recovered from the kunkar beds, but these were unidentifiable.

From the sequence of deposits exposed in the two sections one sees that, when the lowest bed was being formed, arid conditions were already far advanced, for in it there occur bands of gypsum. Since the sands and clays above this gypsiferous horizon contain lenses of gravel, one must conclude that at intervals there was fairly heavy precipitation. On the other hand the bands of ironstone are an indication of a further increase of aridity since the conditions necessary for their formation could not have been disturbed by periodical floods of torrential water. That this was the case is borne out by the absence of gravels from the ironstones themselves, which are sandy, oolitic, or concretionary. The beds overlying the ironstones also contain no gravels.

East of the source of the Semliki the lake shore is bounded by a line of cliffs which afford a fine section of the Kaiso deposits. The beds are chiefly sands and clays passing laterally into one another. The only constant beds are two ironstones which vary from 4 inches to 3 feet in thickness from west to east. Fig. 9 shows the section exposed along the lake shore, and from it it will be seen that the beds are much faulted. Of the faults shown in the section, 1, 3, 4, and 5 were observed, whilst 2 and 6 are suggested as probable. It was difficult to determine the true strike of these faults, but it appeared to be nearly north–south. Fig. 10 shows two sections (X and Y) of these beds at points ½ mile and 1 mile east of the Semliki source. It can be seen that the topmost sand of section X has changed to a green clay in section Y, besides which the incipient ironstone horizon has developed to a band 2 feet thick. The yellow sand occurring between the ironstone horizons in X appears as a brown-green clay in Y, and the lower 4 in. ironstone band thickens to 3 feet. Immediately above this ironstone in Y there now occurs a thin band of gypsum about 1 inch thick. Where the ironstone bands have reached a thickness of a foot or more they contain fossils, mainly mollusca, any other material being fragmentary. It is interesting to notice that the forms of *Viviparus* that occur here, though related to those found on the east side of the lake, and occurring in beds of the same date, have evolved spines and a concave form of whorl.[1] Possibly these modifications, already noted in other parts of the world in connection with *Viviparus*, may be the result of a deep-water habitat.[2]

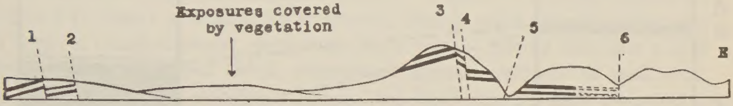

FIG. 9.

About 2 miles east of the Semliki source there is a high cliff in which are exposed two ironstone bands dipping at 20° to the west.

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[1] An evolutionary series of these shells is being worked out.

[2] N. Annandale, *Proc. Roy. Soc.*, Series B, xcvi, No. B. 672.

These must almost certainly be a continuation of the ironstones exposed to the west of the section, but no exposures occur along the intervening shore, as the cliffs are absent and the land slopes gently down to the lake. In section, Fig. 9, faults 3 and 4 are normal faults with the downthrow to the east. On the other hand, fault 5, which can be traced for a short distance up the gully, which has formed as a result of its presence, appears to be a reversed fault hading to the west but with a slight downthrow to the east. Fault 6 like 2 was not seen, but from a distance it appears likely that there is a fault at this point. This section is particularly interesting since it is the only place in the Lake Edward basin in which faults can be seen in a section. The occurrence of so many fractures at this point is probably due to the presence of the Bukuku Hills massif, which has caused the main fault to branch eastwards, at the same time continuing its original direction by means of numerous subsidiaries.

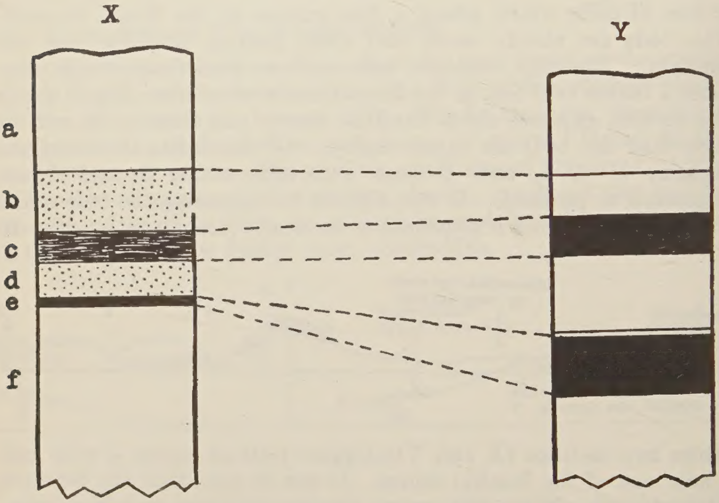

FIG. 10.—a : Humus in both sections. b : Sand in X changing to green clay in Y. c : Sand with ironstone nodules changing to ironstone proper. d : Yellow sand changing to brown-green clay. (In section Y there is a thin band of gypsum at the base.) e : Ironstone (4 inches) thickening to 3 feet in Y. f : Sandy-clay changing to clay.-

From a comparison of the exposures of the Kaiso beds round Lake Edward with those round Lake Albert we see that during the early Pleistocene large lakes existed in the western rift. In them lived a distinctive fauna, which has been preserved in the upper part of the lake beds that were deposited in these basins. As already stated, towards the end of the Middle Pleistocene the area became increasingly arid and finally dried up completely. The beginning of the Upper Pleistocene was then heralded by a renewal of the earth movements accompanied by volcanic activity and a rapid return of heavy precipitation over the whole area.

(*b*) *The Deposits of the Second Pluvial* (*Gamblian*) *in the Lake Edward Basin.*

With the advent of the Second Pluvial the now modified lake basins began to fill once more, and to them there came a new fauna quite different from that which had existed during the First Pluvial. The deposits of the Second Pluvial Period in the western rift correspond in time to those of Gamblian and later age in the eastern rift, hence for want of a local name they are, in this paper, referred to as Gamblian.

In the Lake Edward basin itself, deposits of this date are not widespread, except in the form of the ashes, which, as already stated, overlie the Kaiso beds all round the northern end of the lake, from the Semliki to the Mwaya peninsula.

The most interesting occurrence of these beds is found at the source of the Semliki, where in section, Fig. 8, they are seen as old river deposits lying on the Kaiso Series. There, in all the exposures, a 2 to 3 ft. band of coarse river gravel, that is calcareously cemented to form a conglomerate, occurs at their base. Above this lies a bed between 1 and 2 feet thick, composed almost entirely of mollusca, mainly *Viviparus unicolor*. These two beds are capped by several feet of coarse sand and alluvial matter which in places may contain a large amount of calcareous material in the form of kunkar. In places the shell band may be absent or may occur below the gravel.

These deposits were evidently laid down by a river flowing into Lake Edward, for as the gravels occur at the present day actually at the point where the Semliki flows out of Lake Edward, they could not have reached their present position through the agency of a river flowing in the direction that it does to-day. In view of this one must suppose that at one time there was a river flowing into the lake at the point where the Semliki now derives its source. This original river was evidently flowing into the lake during the Second Pluvial, for the molluscan fauna, contained in the deposits laid down by it, is of Gamblian date. This fauna must have reached Lake Edward from Lake Victoria via the rivers that rise in the "swamp divide"[1] due to river reversal by earth movement. Further evidence showing that the Semliki once flowed into Lake Edward is found in the form of a large underwater delta that stretches out into Lake Edward from the point where the Semliki now has its source. Up to half a mile from the shore there is no more than 3 metres of water, but after that there is a gradual deepening to 30 metres at 3 miles. Just south of this area and only 2 miles from the shore a depth of 97 metres was recorded. Another point is that the rivers Kunyamiga and Museya join the Semliki at an acute angle with the apex pointing to the south which leads one to believe that the main stream originally flowed towards the lake.

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[1] E. J. Wayland, *Summary of Progress of the Geol. Surv. of Uganda*, 1929, 41.

The reversal of the Semliki could have been brought about by earth movement,[1] but the evidence points to river capture. The Karungu Hills are the only high land on the floor of the Semliki Valley, and it was in these hills that the original southward-flowing Semliki, and the northward-flowing river, must have had their sources. The fall of the Semliki from this point to Lake Edward can only have been 200 or 300 feet, nearly all of which occurred in the first few miles of its course. On the other hand the fall of the northerly river flowing into Lake Albert (2,000 feet) was over 1,000 feet at the very least, and this fall was evenly distributed over the length of its course. In consequence, the cutting of the northern river took place much more rapidly and it captured the southern river, after having cut a sheer-sided gorge through the gneiss on the edge of the Karungu Hills. When the capture of the headwaters of the Semliki had been effected and the source of the northern river brought below the 3,000 ft. contour, reversal took place, and the volume of water pouring out of Lake Edward added to the erosive powers of the river which has now cut back the 3,000 ft. contour for a distance of 25 miles to Nabugandu, which is only 8 or 9 miles from Lake Edward. On the map (Fig. 6) this contour can be seen to follow the course of the river closely on either side.

The Semliki Source Bar.

At the present time the Semliki flows out of Lake Edward over a hard sandstone bar. It was at first thought that this was a member of the Kaiso Series exposed in the nearby cliffs. Later it was found to contain mollusca belonging to the present-day fauna of the lake. On further investigation it was found to be a deposit formed comparatively recently on the edge of the lake. When investigating the Kaiso beds at Kateta on the east of the lake, some boulders of a calcareously-cemented sandstone were noticed near the water's edge, but their place of origin could not be found. Then again at Kaianda, to the north of the lake, curious slabs of calcareously-cemented sandstone occur along the shore dipping towards the lake at the same angle (about 10°) as the sandy beach. Finally, at the source of the Semliki, and for some distance north and south of it, a calcareous sandstone was again found. In general it dips towards the lake at the angle of the shore slope, but in some places, where wave action has undermined it and the mass has become broken up into large and small blocks, the angle of dip has been altered. It therefore seemed probable that these deposits were the result of the cementing of the sand on the lake bottom near the shore. The calcareous material in the case of the Semliki deposits might have been derived from the numerous mollusca found in the sand, or as a precipitate from the lake water itself. But in spite of the shells of the mollusca being completely dissolved, it seems unlikely that these were the source of the calcareous cement, for the forms of the shells are preserved by the cementing material itself. Then in the case of the similar deposits at Kaianda and Kateta, no casts of mollusca could be found in the rock. If the cement was derived from the lake water it must have been precipitated either by an increase in the alkalinity of the water as a whole, or as the result of the extraction of carbon dioxide by vegetation living in the water. Such an increase in the alkalinity of the lake water might have been brought about by a sudden influx of primary water charged with salts, as for instance in connection with the volcanic region to the north of the lake, or by rivers such as the Ruchuru whose waters are known to be fed from volcanic sources, and to be more alkaline than that of the lake.[1] On the other hand, since it is known that lakes with a strongly-marked thermocline [2] tend to have the upper layers heavily charged with calcium carbonate, it seems more probable that the extraction of carbon dioxide was the cause of precipitation.

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[1] E. J. Wayland, *Compte Rendu, XV Session, International Geological Congress,* 1929, p. 351, section (6).

It is noteworthy that the particles of sand in the specimen obtained from the Semliki have a remarkable form of fracture and are quite unrolled, besides which the felspars and the ferro-magnesian minerals are perfectly fresh, which gives the sand every appearance of being the result of weathering under desert conditions. This is accounted for when it is realized that the source from which the sand was derived was the gneissic walls of the rift, only a few miles to the west. Therefore, though the sand was possibly formed under desert conditions, just before the beginning of the Second Pluvial, the distance of transportation from its source to the delta of the original Semliki River was so short that the grains would not have become rolled.

As already stated, this sandstone forms a bar across the source of the Semliki and in this way prevents the river cutting farther down through the soft clays and sands of the Kaiso series. Directly this barrier is overcome the downward progress of the river will be very rapid, and the result will be the disappearance of Lake George (now, except for a crater, only 8 feet deep) and the partial draining of Lake Edward.

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[1] H. E. Hurst, *The Lake Plateau Basin of the Nile*, Egyptian Gov. Publication, Cairo, 1927.

[2] L. C. Beadle, *Linn. Soc.*, xxxviii, 258, Oct., 1932, 186.

III. THE KAZINGA CHANNEL.

The Kazinga Channel is a stretch of water that forms a connection between Lake George and Lake Edward. It is about 30 miles long and varies between $\frac{1}{2}$ and $\frac{3}{4}$ of a mile in width. The lakes are so nearly at the same altitude that there appears to be no flow of water between them. However, it was shown by floating bottles [1] that there is nearly always a current in the channel, but that this may vary its direction. It seems that an increase of precipitation on Ruwenzori, whose eastern flanks drain into Lake George, causes a flow of water into Lake Edward. On the other hand, when the evaporation from the very shallow Lake George (maximum depth 8 feet) exceeds the supply from the rivers, the flow of water in the channel is reversed.

(*a*) *The Formation of the Kazinga Channel.*

From the evidence seen, the following is put forward as the most probable history of the formation of the Kazinga Channel. With the on-coming of the Second Pluvial Period both the Lake George and the Lake Edward basins began to fill, and at the same time sediments were being laid down. These belong to the Gamblian Period, which starts with the beginning of the Second Pluvial. Hence it is not surprising to find the Kazinga Channel, though itself of Gamblian date, cutting through Gamblian deposits. As the Lake George basin was comparatively shallow, the water rapidly encroached on the gently shelving southern shores and soon began to overflow into the Lake Edward basin which had been deepened by the post-Kaiso faulting. In consequence the water level was at first lower than that in the Lake George depression. To begin with the water seems to have flowed gently as a wide strip (possibly as much as six miles wide) which formed a very shallow channel; then as the fall became greater, owing to the continuation of faulting in the Lake Edward basin, the velocity increased and the channel was cut deeper and narrower. Thus, every time movement took place along the fault lines in the Edward basin, one would expect a corresponding down-cutting in the Kazinga Channel. It is possible to trace four levels on either side of the Kazinga Channel, but the lowest will be shown to have been formed for a different reason. It is therefore possible to conclude that there were three periods of movement during the early part of the Second Pluvial, after each of which the water-level of the two lakes succeeded, or nearly succeeded, in establishing equilibrium. It is probable that a certain amount of volcanic activity accompanied each set of movements, and so formed the aqueous ashes and tuffs found round the northern end of the lake.

With regard to the fourth and lowest level found in the Kazinga Channel, it too was formed owing to the lowering of the level of the water in Lake Edward, but this was not brought about by faulting. As already stated, at the source of the Semliki River there are cliffs 35 feet high which have been formed by the cutting of the river through the Kaiso beds. That this had happened since the reversal of the river is evident from the deposits of post-Kaiso date. It would appear that once river reversal had been effected, the cutting of the present channel proceeded apace owing to the softness of the deposits (sands and clays). The consequence of this was the rapid lowering of the lake-level, and the rejuvenation of the Kazinga Channel, which had at this time established equilibrium between the lakes. It does not seem likely that any further deepening of the channel will take place until the Semliki has succeeded in cutting its way through the sandstone bar (already referred to on p. 155) that now holds up its further downward progress. When this happens a rapid deepening of the river bed may be expected, followed by the draining of Lake George and the partial draining of the Lake Edward basin.

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[1] L. C. Beadle, *Linn. Soc. Journ. Zoo.*, xxxviii, 258, Oct., 1932.

(*b*) *Kaiso Deposits of the Kazinga Channel.*

Owing to the overgrown nature of the cliffs and banks of the channel it is impossible to find continuous exposures over any distance, but there are a number of isolated sections.

At the south-western end where the channel enters Lake Edward, it is flanked by vertical banks 120 feet in height. Where these are not too heavily overgrown ironstone deposits may be traced in the sandy clays. The best exposures occur on the south bank. There are fossiliferous ironstones at several levels,[1] but none of them, so far as could be ascertained, extend over a very wide area. The following table gives short particulars of each horizon.

Ironstone band	Thickness	Ht. above L.L.	Fossil remains found	Type of ironstone
No. 3	8 in.	70 ft.	Mammals, Crocodile, Lamellibranchs, Fish, (*Clarias* and *Lates*).	Concretionary or sandy.
No. 2*a*	4 in.	40 ft.	None.	Concretionary.
No. 2	18 in.	20 ft.	Few mammals, Crocodile, Gasteropods (many), Lamellibranchs (few), Fish (*Clarias and Lates*)	Sandy or oolitic.
No. 1*a*	12 in.	16 ft.	Gasteropods and Fish.	Sandy.
No. 1	6 in.	3 ft.	Gasteropods (many), Fish, Crocodile (few).	Oolitic or concretionary.

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[1] These ironstones contained a prolific gasteropod fauna composed of many individuals, but few species. It is hoped to trace an evolutionary series.

Ironstone No. 1 occurs about 200 yards up the channel from the lake, and at several points on the lake shore to the south of the channel mouth. It is not very fossiliferous, and is on the whole oolitic, but at points is of the massive concretionary type of ironstone.

Nos. 1*a and* 2 occur together, being separated by about 4 feet of clay. No. 2 is perhaps the more extensive. They are both highly fossiliferous and are in the main sandy in character though some parts of No. 2 are oolitic.

No. 2*a* is poorly developed, occurring at two or three points a short distance east of the last exposures. It contains no fossils.

No. 3 is by far the most extensive ironstone, occurring on both sides of the channel at its mouth, but though well developed on the south side, it is thin and only slightly fossiliferous on the Mwaya peninsula. An isolated ironstone band at a height of 70 feet above the water occurs on the Mwaya isthmus, about a mile and a half to the north, and may be connected with No. 3. This is very thin and quite unfossiliferous.

All these ironstones occur as lenses in a series of clays and fine sands of Kaiso age.

In the next section exposed in the Kazinga Channel, which occurs at Katanda to the south, there are no ironstones. There the cliffs rise 135 feet above the water, but the lower 100 feet afford no section owing to scree and vegetation. The lowest bed exposed is a white sandstone, in the lower part of which occur some iron-stained calcareous nodules. Above the visible 5 feet of this sandstone there are 2 feet of iron-stained clay followed by 4 feet of yellow clay, on which lies a very thin band of oolite about 1 inch thick. On the top of this comes 18 inches of a fairly coarse gravel, and then a final capping of 20 feet of kunkar.

The remaining exposures of Kaiso beds in the channel show a similar type of succession and apparently there are no further ironstone bands, except possibly at the point marked X on map (Fig. 6) where a brown band seen from the water, but which it was impossible to investigate, might prove to be one.

At Katunguru, where the road comes down to the ferry, there are two sections of the deposits visible, one on either side of the channel. Only that on the west side exposes Kaiso deposits, and these are doubtfully of that date. The beds thought to be of Kaiso age are the lower 24 feet consisting of micaceous sands and clays. The upper beds are non-conformable, for there is an erosion surface. It is the occurrence of the 15 feet of coarse yellow sand with lenses of gravel that casts a doubt upon the age of these lower deposits, for it has too much the appearance of a river deposit.

North of Katungu there is only one other section in which beds of Kaiso age were seen, this is in the gorge cut by the Chambura river, where the succession is :

40 feet ash (containing plant remains).
20 feet sand.
40 feet clay.

It is thought that both the clay and sand are of Kaiso age but that the upper 40 feet of ash is Gamblian.

(*c*) *Deposits of the Second Pluvial* (*Gamblian*) *of the Kazinga Channel.*

At the south-west end of the channel no deposits of definite Gamblian date were found other than ashes, and these do not occur on its immediate flanks. On the other hand at the north-east end there were no beds of Kaiso age, every section exposing Gamblian only. Evidently the Gamblian deposits overlap the Kaiso from north to south. Those deposits of Gamblian or later age which formed in the channel itself are now cut through by the rejuvenation of the channel due to the reversal of the Semliki.

At the north end of the channel, wherever exposures occur, they are composed entirely of aqueous tuffs. Near Lake Chinona, which appears to have been a crater originally, no tuffs or ashes could be found, for the ground slopes gently to the water, the surface being covered with sand and gravel.

In the gorge of the Chambura River there occur 40 feet of ashes believed to belong to the Gamblian. The upper part of these ashes have yielded a few fossils which have nowhere been recorded before Gamblian times.

On both sides of the channel up to a distance of 5 miles on the east, and about 3 miles on the west, the deposits forming the land surface are aqueous ashes often containing large quantities of plant remains. These are all of Gamblian date and were apparently laid down in shallow pools or marshes.

At Katunguru Ferry there are exposures on both sides of the channel where the track comes down to the water. On the east, there is a cliff of false-bedded sands banked against an older series of sandy clays in which occurs a band of hard white limestone 18 inches thick. Though the limestone and clay cannot be seen banked against beds of Kaiso age, it is supposed that this is the case, for the limestone contains land and lacustrine gasteropods of Gamblian date, and would seem to have been formed in the channel just before the reversal of the Semliki. It is suggested that the sands were river sands brought down by the Chambura River, for, in spite of the cessation of erosion in the channel, the river would continue to flow and to bring down material, which instead of passing on with the current of the channel as before would be deposited immediately it reached the quiet water.

On the west side of the channel the section is composed of Gamblian sands, clays, and ashes in the upper part, whereas the lower 24 feet exposed may be of Kaiso age.

IV. THE LAKE GEORGE BASIN.

Lake George lies in a small eastern branch of the rift valley. North of the lake the rift faults die away or are hidden by the tuffs of the Toro volcanic area. The lake itself is very shallow, having a maximum depth of only 8 feet. It receives most of its water from the eastern slopes of Ruwenzori, but to the north-east the Mpanga River brings water from the Toro district and from the "Swamp Divide" near the headwaters of the easterly-flowing Katonga. The outlet is the Kazinga Channel.

As previously stated, a large lake existed on the site of the present basins of Lakes George and Edward. The faulting that affected the Lake Edward basin is not so apparent round Lake George, though the whole Lake George block has apparently tilted to the north. The general instability of the rift floor at that time is shown by numerous small explosion craters that have been said to mark the position of ancient faults. The craters occurring at the south end of Lake George are comparable to those at the north end of Lake Edward. They form a recognizable belt across the rift valley, of which the most westerly is Lake Kikorongo. From there travelling eastwards comes Bunyampaka, followed by the Masecha-Bagusa group. All these are marked on the Uganda Congo Boundary Commission Map of 1908, because they contain crater-lakes; but there are also several other dry ones which are not marked, and which occur in the same line. One lies about a mile north-west of Bunyampaka and another south-east of that lake, near to the Kazinga Channel. Then to the east of Lake Masecha there are two deep dry craters close to one another, neither of which appear on the map, but belong to the series.

The activity of all these craters took place at the beginning of the Gamblian, and the resultant tuffs have masked any Kaiso deposits that might have appeared in the district, in just the same way as has occurred at the north end of Lake Edward.

(*a*) *Kaiso Deposits of the Lake George Basin.*

Deposits of Kaiso age in the Lake George basin are scarce and were only recorded at a few isolated places.

(i) *Kaiso Deposits East of Lake George.*

On a journey up the east side of the lake, in the Chikombi area, there was a steep ridge, the top of which was composed of gravel. The ground was so overgrown that it was impossible to make out any succession, but the whole seemed to be built up of a series of clays and gravels. The flat top lies at 170 feet above the lake (aneroid), and it is thought that these gravels must have been laid down in the old Lake Edward-George.

(ii) *Kaiso Deposits North-east of Lake George.*

To the north-east of Lake George, where three rivers are marked flowing into the lake from Haragat Mountain, there are numerous flat-topped hills. The uppermost 100 feet of these hills consists of a hard gritty ironstone in which there occur worm holes. No fossils of any kind could be found. Here, as in other places where rivers flow over Kaiso beds, there was a tendency for deep gullies to be cut back from the lake shore by underground seepage, whilst the normal watercourses from the escarpment behind gradually diminish in size as they approach the lake. For these reasons and because of its height above the lake (220 feet approximately) the ironstone that caps these hillocks must be assigned to the Kaiso period.

(iii) *Kaiso Deposits West of Lake George.*

For further deposits of the same date one must look to the west of Lake George, where on the west of Lake Kikorongo and for some distance northwards along the foot of the Ruwenzori range there occurs a terrace of gravels and clays sloping gently eastwards, but ending abruptly with a steep front. Here for the first time it was possible to record a section through some of these deposits. They are an alternating series of sands and clays with lenses of fine and coarse gravels. Immediately west of Kikorongo Lake there is a vertical-sided gully giving another section through these deposits. Here they are more homogeneous, being mainly yellow sands with kunkar and a few lenses of gravel. There are two ironstone bands at 60 feet and 100 feet (approximately) from the bottom of the section. They appear to be unfossiliferous, but, as it was impossible to approach them nearer than 25 yards, this is uncertain.

These gravels seem to correspond in date to the ironstone on the east of the lake, for they occur at 255 feet above the water, compared to 220 feet for the ironstone. Unfortunately these heights are not reliable as there was no means of checking the aneroid at this time.

Whether either or both of these deposits have or have not been faulted, it is impossible to say. Certainly they have such an appearance, for they both end abruptly on the flank towards the lake. If this is the case it is difficult to know to what age to assign the faulting. Possibly it was connected with the early Middle Pleistocene movements.

(*b*) *Deposits of the Second Pluvial* (*Gamblian*) *in the Lake George Basin.*

The Gamblian deposits of the Lake George basin, though widespread, are very poorly exposed. The reason is that deposition has continued up to the present day, and a blanket of recent alluvial matter now covers any lake deposits that might have been seen, in the same way as has happened at the south end of Lake Edward.

(i) *Gamblian Deposits East of Lake George.*

On the east shore, from Mayura northwards, there is evidence of the retreat of the lake in the form of old beaches at 35, 60, and 85 feet above the present level of the water. The 85 ft. level is not persistent and only appears where the Nkurungu River has formed a delta fan. From the flat form of the top of this fan it appears to have been formed under water. This level may be comparable to the 110 ft. level of the Kazinga Channel, in which case it indicates a northerly subsidence of the Lake George block after the formation of the delta, and before that of the 60 and 30 ft. levels, which correspond to the lower two of the Kazinga Channel. No sections through the beaches could be seen, but it was noticeable that they did not seem to contain any volcanic material.

To the south of the lake there are numerous craters, and the exposures show nothing but tuffs; but to the south-west in Lake Bunyampaka crater there is an exposure of lake deposits other than tuffs.

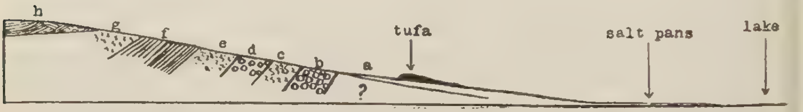

Fig. 11.—Diagrammatic Section through the north wall of Bunyampaka crater. a: Alluvium. b: Calcareously cemented gravel. c: Bed of small kunkar nodules. d: Gravel. e: Kunkar with quartz grit. f: Volcanic ash. g: Kunkar deposit. h: False bedded ash of later date than the deposits b–g.

(ii) *Gamblian Deposits in Bunyampaka (Kisenyi) Crater south-west of Lake George.*

The crater is situated to the south-west of Lake George, and having no cone consists of a circular depression in the lake deposits, about 125 feet deep. The sides are not precipitous but slope gently inwards. The water of the lake is a saturated salt solution.

Walking down the path from the village on the north edge of the crater to the water, one first passes over a false-bedded ash which has a high content of fine gravel, in places concentrated by current action; then over a deposit of kunkar, beneath which lies another ash. Below this point no further ashes are visible in the wall of the crater. In the section, Fig. 11, except where covered by alluvium and a tufa deposit, the remainder of the exposed beds are seen to be sand, gravel, and kunkar.

The topmost ash, with the exception of the alluvium and tufa, is evidently of later date than the rest of the beds in the section. It is supposed that this ash was the product of the explosion that formed the crater, and that the other beds were present in a horizontal position before the explosion took place. All these beds appear to be Gamblian, and no Kaiso beds are thought to occur in this section. The tufa that occurs between 25 and 50 feet above the lake has been deposited either by streams of primary water or by water from Lake George charged with calcium salts as a result of its passage through the surrounding lake deposits.

(iii) *Gamblian Deposits West of Lake George.*

On the west of Lake George, from the foot of the Kaiso gravels, the ground slopes so gently towards the lake that it was impossible to locate either the 35 or 60 ft. levels.

Where a section 20 feet deep was exposed by the Mohokya river the whole was composed of recent alluvial matter, and it is likely that all the low-lying ground to the north of the lake is also formed of such recent material.

To the west of Kikorongo crater-lake it is possible to walk up a ridge between two dry explosion craters on to the top of the Kaiso (?) deposits already mentioned. They are here capped by several feet of fine tuff dipping eastwards at an angle of 20°. The tuff is evidently not far from its source, for on its surface is a thin layer of coarse angular fragments of volçanic rocks that have been left after the removal of the finer material by wind and water.

(*c*) *Additional Notes on the Lake George Area.*

(i) *The Eastern Rift Wall near Lake George.*

The rift wall is here formed of gneiss with pegmatite veins and dolerite dykes that cut through it more or less vertically in a general east–west direction. In this respect it is similar to the Ruwenzori mass. When looking at the almost sheer scarp from a distance, it is noticeable that all the small streams that run steeply down it have cut little gullies into its face at the same level, i.e. about 500 feet above the lake. It was found that the beginning of these gullies marked a line above which the slope of the escarpment was very much less. When looking along this line towards the south, it seemed to be continued in the far distance by some markedly flat topped hills. It is thought that it may correspond to Wayland's " hanging base line " of Ruwenzori.[1]

(ii) *Lake Kikorongo.*

Like Katwe and Bunyampaka, Lake Kikorongo is a crater lake, the crater having been formed by an explosion through lake beds. Here, as in Katwe, there are numerous ejected blocks showing the nature of the pipe through which the explosion took place. The crater wall is highest on the west, where it reaches about 100 feet above the water, and lowest on the east where it is only 25 feet high. The water of the lake has a very high soda content, and at the present time there are no fish living in the lake, though in 1905 Mr. R. E. Dent recorded the existence of *Tilapia.* This matter is discussed by Mr. L. C. Beadle,[1] and he also gives tables of the alkalinity of the lake in 1920 and 1930. Evidently this has recently increased enormously and in spite of the explanation that during the wet season the fish (particularly *Clarias*) can obtain access to the lake via marsh and stream that then connect it to Lake George, there is evidence of the permanent retreat of the lake from its original level in the form of a 25 ft. beach round a large part of the circumference. At the time of the formation of this beach, Kikorongo must have been connected with Lake George, for precipitation alone over the small area that drains into the crater-lake could scarcely be sufficient to maintain it at this level, with an overflow at the low east wall. This shows that apart from seasonal fluctuations, or even fluctuations over a period of years, there has been a persistent fall in the water level. The last year of exceptionally heavy precipitation was 1930, yet already in July, 1931, when the expedition visited the lake, the water level could not have been more than a foot or two above its minimum. There is a considerable quantity of water flowing into the lake by means of numerous small springs on the north shore. As many as fifteen occurred within 20 yards. Beadle found that the water of these springs was of less alkalinity and salinity than that of the lake. This, and the fact that there are no springs on the east, west, or south shores, leads one to believe that this water is derived from Lake George. Round the springs there is a considerable mass of tufa which has been deposited by them. If Lake George is their origin, the amount of water brought by them to Kikorongo must be governed by height of the water in Lake George. Therefore not only the height of the water in Lake Kikorongo but also its degree of alkalinity is dependent upon the fluctuations of Lake George.

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[1] E. J. Wayland, *Petroleum in Uganda*, fig. 8.

V. THE KAISO DEPOSITS WEST OF RUWENZORI.

During a journey into the Belgian Congo to the Semliki River, in search of the falls near Beni, a few exposures have enabled the accompanying section, Fig. 12, to be drawn. Since the whole of the country is covered by either elephant grass or dense forest, the exposures are few and far between.

Having crossed the southern nose of Ruwenzori the path leads northwards along the base of the western foothills. Numerous streams running off the mountain have cut deep steep-sided gullies into the low-angled slopes of talus. Presently, turning west, the way leads down these slopes for some miles, when they flatten out into a plain. Crossing this plain from north to south were several shallow stream-beds. To the north-east of the Karungu Hills there were three river-beds of considerable size, the largest having very steep sides and a depth of 250 feet. From the sections exposed in these gullies it was seen that these rivers have cut into a series of lake beds, which, with the exception of an uppermost deposit of carstone, are entirely composed of sands and clays. The clays are light coloured or even white, and are largely formed of kaolin from the gneisses of the Karungu Hills. Unfortunately none of the deposits was found to be fossiliferous. There is little doubt that they are of Kaiso age, and are, in fact, the northern continuation of the Kaiso deposits found in the Bwamba country. The existence of these deposits was suggested by Mr. A. D. Combe[1] in 1925.

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[1] L. C. Beadle, *Linn. Soc. Journ., Zoo.*, xxxviii, 258, Oct., 1932.

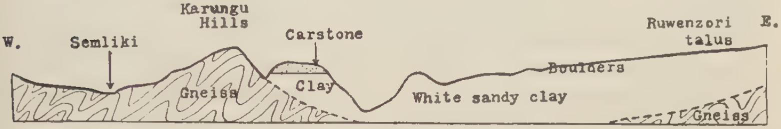

FIG. 12.—Section through the Kaiso deposits West of Ruwenzori. Vertical scale, 1 in. = 1,000 feet. Horizontal scale, 1 in. = 2¼ miles.

C. CONCLUSION.

It has been seen in the foregoing that the sequence of events during the Pleistocene in the western rift is almost an exact repetition of that in the eastern rift valley. However, the rift valley lakes of Uganda, unlike those of Kenya, all have outlets and consequently their levels are nearly constant. In spite of this, there is evidence to show that during the Pleistocene there have been two periods of heavy precipitation between which there was one of such extreme aridity as to cause the extinction of the existing faunas (at least that part of them directly dependent upon the lakes and waterways). With the second of the wet periods (Gamblian) another fauna appeared in East Africa. Its origin was the Nile and it has persisted in the lakes until the present day,[2] and had given rise to numerous nearly related endemic forms. It is noticeable that those animals which bridged the gap formed by the dry period, and reappeared in the area during the Gamblian, were not for the most part directly dependent upon an aquatic environment, but were able to move farther afield in search of more congenial conditions during the dry period. This indicates that, although in East Africa and North Africa[3] these arid conditions were widespread, in other areas, probably both to the south and west, the existing conditions were little disturbed, so that it was to these parts that the animals were able to retreat.

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[1] A. D. Combe, *Annual Report*, 1924, *Uganda Geol. Surv. Dept.*, p. 7.

[2] This subject has been discussed from the faunistic point of view by E. B. Worthington, *Geogr. Journ.*, lxxix, 1932, 287, and *Inland Waters of Africa*, 1933, chapters 14 and 15.

[3] Miss E. W. Gardner.

From the Gamblian deposits round the lakes of the eastern and western rifts it has been seen that the second Pluvial Period is drawing to a close, in spite of seasonal and periodical increase in the precipitation. In the eastern rift Leakey has recognized two post-Gamblian wet phases, the Makalian and the Nakuran. In neither case did they fill the lake basins to anything approaching their former extent. Since the beginning of the Gamblian period the lakes have been rising and falling, but even the recognized wet phases have been successively less and less marked, so that one must consider the possibility of another period of intense desiccation in the relatively near future. So short a time ago as 3,000 years, Lake Nakuru[1] was 145 feet above its present level. If the fall of the lake were to continue at this rate, it would be dry in two hundred years, for at the present time it is no more than 9 feet deep. Taking the other lakes in the Kenya rift we find that their depths are :—

Rudolf	240 feet
Baringo	20 feet
Hannington (very shallow) . .	?
Nakuru	9 feet
Elmenteita	6 feet
Naivasha	30 feet

The fall of the lakes is an indication of reduction of precipitation, and when the lakes are dry it will be because the rivers are dry. We have only to look to Lake Rudolf, where precipitation has been reduced to 10 inches or less in the year, to find a desert area which, but for the lake, would be unable to support a population of any kind. The vast areas of the Kenya plains are tending towards a similar condition, so that, with the exception of the highlands over 6,000 feet, the prospect of Kenya within the next two centuries is indeed a poor one.

In Uganda matters do not seem to have progressed so far, for the fall in the lakes can to a large extent be attributed to physiographical causes, such as river capture and earth movement. However one cannot expect that Uganda will be unaffected by the increasing aridity of the Kenya climate. Furthermore, examples have been cited of how erosion is leading to the loss or reduction of lakes, which will inevitably tend to a further reduction of precipitation, so that the future does not hold out a roseate future for an agricultural population.

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[1] L. S. B. Leakey, *The Stone Age Cultures of Kenya Colony*, 247.

Some Spherulitic Growths from Queensland.

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(PLATES VIII–X.)

I. INTRODUCTION.

THE object of this paper is to bring before the notice of those interested a number of examples of spherulitic structures which seem to throw some light on the nature of the processes by which spherulites, lithophysae, and pyromerides are formed.

It is not the present intention of the writer to deal with the spherulitic rhyolites of Queensland in systematic fashion or to describe in detail those characters normally found in such rocks. Rather is it his purpose to select for treatment certain specimens which, by their very regular development or by the possession of some significant feature, are of special interest in the study of spherulitic growth.

It is not thought necessary to consider here the history of the development of ideas on spherulites and spherulitic growth. Readers are referred to the excellent historical review by Whitman Cross (1) [1] and to the recent bibliographies in the works of A. Johannsen (2) and A. E. Mourant (3). It will be sufficient here to distinguish between those points relevant to this paper about which there is now general agreement and those other points which are still the centres of controversy. It is now held by most authorities that :—

(1) Spherulitic structures are due to rapid crystallization in a highly supersaturated viscous solution ;

(2) The essential characteristic of spherulitic growths consists in the formation of radiating or diverging groups of crystals which grow outwards from one or more points ;

(3) Many spherulites were formed after the enclosing lava had cooled to a nearly solid state.

With regard to the nature of the cavities in hollow spherulites and the origin of lithophysae there have been and still are great differences of opinion. These have been ably summarized by F. E. Wright (4), who shows that the origin of the cavities has been assigned to :—

(1) The chemical and mechanical alteration of solid spherulites and the removal of much of the original material ;

(2) The expansion of gas bubbles liberated during the crystallization of the spherulites forcing out the walls of a cavity ;

(3) Gas bubbles escaping from the cooling magma around which spherulitic growth takes place ;

(4) Hydrostatic tension developed by the shrinking of a magma during cooling.

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[1] The figures in parentheses refer to References at end of article.

The first explanation in this list has been generally abandoned so that we are left with hypotheses based on gaseous pressure on the one hand and that based on hydrostatic tension on the other. The latter explanation is almost universally accepted at the present day. This is due to the convincing nature of Iddings' (5) classic work on the spherulitic structures of Obsidian Cliff. Nevertheless Wright (6) as a result of his detailed study of lithophysae from Iceland concluded that " In most cases it is probable that both factors, contraction of the cooling magma and gas pressure, have been active " and that " in the case of the Icelandic lithophysae the pressure of the liberated gas was an important factor in the development of the cavities ".

While most writers are agreed that the siliceous material (chalcedony, agate, " flint ", or quartz) frequently found more or less completely filling hollow spherulites is of a secondary nature due to the subsequent infiltration and deposition of silica, the view has sometimes been held that such siliceous material is of primary origin. Thus Dr. Ida Brown (7) concludes that in certain large specimens from the South Coast of New South Wales " the spherulite appears to be a secondary structure developed about the original geode ".

II. THE NODULAR SPHERULITES OF TAMBOURINE MOUNTAIN. (See Plate VIII (1A and 1B).)

(a) *Description.*

The first specimens to which attention is drawn are found associated with rhyolites of supposed Tertiary age developed at Tambourine Mountain in the south-eastern part of Queensland. Here, in addition to the more normal spherulitic phenomena, are found certain bodies which may be termed " nodular spherulites ". These objects vary in size from less than 1 inch to as much as 10 inches in diameter. While exhibiting considerable variety these nodular spherulites have in common certain characteristic features. In appearance they are roughly spherical in shape, but in contour they depart from that of simple spherulites by the occurrence of a number of rounded prominences which often give the specimen a nodular or mamillated appearance. These prominences vary from 6 to 14 in number, and each appears to be an isolated portion of a regular sphere. These regularly rounded portions are each limited on the surface by a polygonal network of cracks or raised lines and are separated from each other by interstitial areas somewhat irregular in shape and curvature. (See Plate VIII (1A), Fig. 2*a*.)

When broken or sectioned each nodular spherulite presents its individual peculiarities, but these for the most part may be considered as variations from some such regular geometrical construction as that illustrated in Text-figure 2, which is a diagrammatic representation of the large specimen on Plate VIII (1A). Essentially the structure is that of several (commonly five) broad sectors such as *Pa'bQ* made up of interlacing quartz and felspar fibres directed towards but not reaching the point *O*. More or less completely filling the space within and between these sectors is a somewhat stellate mass of siliceous material.

A closer examination shows that each broad sector is a composite structure made up of an inner sector *A′a′bB* (lying beneath the prominence *A′B*) flanked on each side by lateral extensions *A′a′P*, *BbQ* (lying below the interstitial areas *AA′*, *BB′*). In each inner sector the branching felspar crystals are arranged in sheaves or groups, which appear to radiate from a point *O* within the spherulite but not at its centre. The inner extremities of the sectors are sometimes limited not by a point but by an arc *a′b* the centre of which *O* would be fixed by the inward prolongation of the radiating fibres, and the curvature of which is approximately concentric with the outer arc *A′B* of the sector. The inner limits of the several sectors would fall on a circle with its centre at *x* the heart of the spherulite. The lateral extensions *A′a′P*, *BbQ* are composed of similar fibrous spherulitic growths but the felspar fibres are usually arranged on a somewhat different plan. In place of regular radiation from a point these felspars, although they show at first a parallelism with the outer sheaves of the inner sector, may gradually become more divergent until they reach the limiting points *P*,*Q*. In some cases it is difficult to see the lines of junction *A′a*, *Bb* between the inner sectors and the lateral extensions but in other cases the junctions are clearly marked.

Within and between the sectors just described and sharply separated from them is a mass of siliceous material. This is commonly chalcedony or agate in the outermost parts, but usually the inner part is of quartz, which may completely fill the remainder of the spherulite or in which well-formed crystals of quartz may project into a central cavity. (See Plate VIII (1B), Fig. 1.)

When separated from the spherulite proper the outer surface of the siliceous material shows a regular and well-marked fluting where it has been moulded against the radiating fibres of the spherulitic growths.

Cracks through the sectors are not continued into the siliceous material but are intercepted by it.

While some of the nodular spherulites may not show all of the above features the modifications observed do not seem sufficiently important to invalidate the composite account that has been given.

Spherulitic structures closely resembling in one or more features those described above have been recorded from time to time.

Miss Catherine Raisin (8) in 1889 in a paper " On Some Nodular Felstones of the Lleyn " referred to " agate nodules " with " radial crusts " and pointed out that " The interior of the nodule is in many cases filled with chalcedony, . . . it is sometimes rounded and amygdaloidal, often it is irregular and may be somewhat stellate ".

Whitman Cross (9) in his classic paper published in 1891 referred to " Hollow Spherulites " some of " boytroidal " structure.

J. Parkinson (10) writing in 1897 on " The Pyromerides of Boulay Bay " stated that a mamillated appearance is rather characteristic of these objects which appear as nodules covered with imperfectly differentiated buds.

More recently Dr. Ida Brown (11) has described somewhat similar spherulitic growths from the Devonian rocks of the South Coast of New South Wales.

(*b*) *Hypothesis as to Growth.*

A general examination of a number of the nodular spherulites of Tambourine Mountain and a more detailed study of the particularly symmetrical specimen shown as Fig. 1 on Plate VIII (1A) have led the writer to the formulation of the following hypothesis as to the growth of these objects.

Text-figures 1 and 2 have been prepared to represent in idealized form two stages in the supposed development.

A simple spherulite developed by outgrowth about a central vesicle until it had reached the dimensions shown in Text-figure 1. The radiating fibres were arranged as though each bundle were directed from the centre *O*. As a result of the internal pressure of gases set free during this early growth, the simple spherulite split into a number of sectors along the lines *Aa*, *Bb*, etc. These sectors were slowly forced away from their common centre and simultaneously pushed apart from each other. This movement provided new surfaces *A'a'*, *Aa*, *B'b*, *Bb*, etc., on which new spherulitic growths rapidly took place. The earliest fibres of this supplementary growth in the areas *A'a'P*, *BbQ*, etc., were parallel to those of the fractured sectors but as the movement developed the new fibres tended to be more and more divergent until, in the outermost portions *P*, *Q*, etc., the shortest fibres were arranged in directions quite independent of those of the primary fibres of the inner sectors. At some later stage the regular stellate cavity thus formed was more or less completely filled as a result of siliceous infiltration.

It is probable that in the special case here considered the uniformity of conditions was very unusual. A very homogeneous spherulite, a very regularly increasing fracture, and a very uniform supplementary growth resulted in an almost perfect geometrical arrangement. With less regular relationships of the controlling factors the many irregularities seen in the nodular spherulites can readily be understood. Indeed, every variety could be explained from simple spherulites with small central cavities to much inflated nodules almost warranting the term lithophysae, and from those in which the radial sectors may be blunt and few in number to those in which they are acute and numerous. (See Plate VIII (1A and 1B).)

The hypothesis explains, too, how some of the felspars have the appearance of being short *ingrowths* normal to the exterior but not strictly radial, and in addition shows how fracture may take place in the spherulite and yet no fractured surfaces be left as evidence (owing to their having been "healed" by the supplementary spherulitic growth).

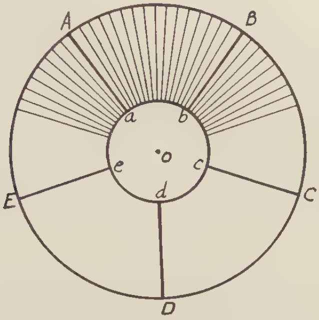

Fig. 1.

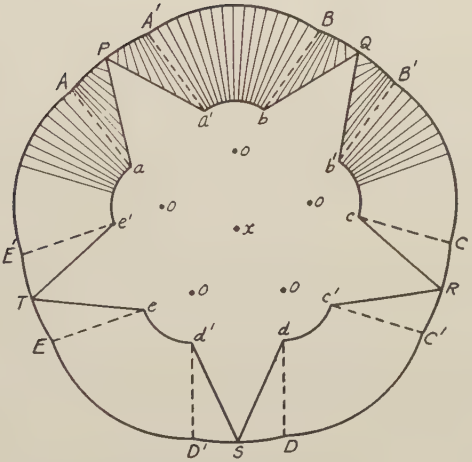

Fig. 2.

Apart from the nodular spherulites it is possible that many of those described in the literature as "compound spherulites" may have developed in this manner.

Should one sector of a minute nodular spherulite become more or less isolated from the remainder of the spherulite, supplementary growth might very well give rise to the "mushroom-like bodies" described by Cole and Butler (12) in 1892, or to structures such as that figured by Iddings (13).

Certain features of this hypothesis had been anticipated by Miss Raisin (14), who stated in her most interesting paper that in the development of the " agate nodules " fissures were formed, both radial and concentric, as part of a general system of brecciation and that owing to the radial cracks a sector might be displaced so as to project beyond the surface of the rest of the sphere. " Such sectors may appear as if they had contracted away from one another at the heart of the spherulite." Miss Raisin also suggested that the stellate outlines may be connected with these radial cracks. It will be seen that Miss Raisin made no reference to the general outward movement of the sectors or the supplementary spherulitic growth both of which are essential to the present explanation.

A much closer agreement exists between the views here advanced and those published by Wright in 1915, but these will be considered in the sequel.

III. Spherulitic Kernels of Mount Hay. (See Plate IX.)

The conclusions arrived at as a result of the study of the nodular spherulites of Tambourine Mountain suggested the re-examination of certain specimens from Mount Hay near Rockhampton, where there occur well-developed lithophysal rhyolites. In association with these rhyolites there are found lying on the surface of the ground the strange siliceous structures shown in Plate IX. Although varying in shape and differing in the number of faces developed these objects have several features in common in addition to their being found in the same locality and all being formed of chalcedony. Each face tends towards a circular outline and shows a number of flutings or striae radiating from an elevated or depressed central region. Here and there are found adhering portions of what was presumably a once continuous skin of spherulitic material. This skin is very thin on the margins of the circular faces but increases in thickness as it is traced towards the centre.

In view of all the facts there can be little doubt that these objects represent internal moulds of very hollow spherulites or lithophysae.

The specimen shown as Figs. 3*a*, 3*b*, and 3*c* in Plate IX is particularly interesting not only on account of its wonderfully regular geometrical pattern but also because it would fit neatly into the " square " lithophysa from Iceland which Wright (15) thought was sufficiently unusual to merit the adjective " unique ".

Wright explains this particular Icelandic structure as due to internal gas pressure forcing asunder a spherulite. He writes (16) : " It is important to note that the forcing apart of the cavity was a very slow process. The first rupture took place when the spherulite was small ; the rigid walls of the cubical or irregularly shaped cavity thus formed were constantly forced apart, but continued to grow as crystallization advanced." The present writer would apply this explanation word for word as the probable mode of growth of the lithophysae from Mount Hay.

Fig. 3 of Plate IX approaches the ideal case of the formation of a hollow spherulite by simultaneous outward movement in three directions at right angles, but other more or less regular modes of growth are indicated in Figs. 1, 2, 4, and 5.

It will be seen that Wright's hypothesis is in strict accord with that independently deduced by the author as a result of the study of the nodular spherulites of Tambourine Mountain. Thus the one simple explanation suffices to interpret all the phenomena exhibited by the specimens from Iceland, South Queensland, and Central Queensland. The writer can think of no alternative hypothesis for which such a claim could be made.

IV. SPHERULITIC "BUBBLES" OF TAMBOURINE MOUNTAIN. (See Plate X.)

One specimen collected from Tambourine Mountain presents a structure which appears to be unique. Within a broken hollow spherulite of somewhat complex nature which had been weathered out of its matrix and was found lying upon the surface there were seen a number of axiolitic growths encrusted with numerous bubble-like lithophysae. One of these axiolites was of particular interest since it showed the relationship of these bubbles to the internal structure. (See Plate X.) The axiolite contained no central cavity, and the radiating felspars were arranged in a series of conical bundles of equal size, but the outer surfaces of these bundles instead of uniting to form the smooth convex surface usual in such cases retained their individuality. Some were outwardly terminated by a deeply concave structure of cup-like (sometimes funnel-like) appearance, while others showed hollow stony spheres evidently contained within similar cups or funnels.

Although the point cannot be established by an inspection of the specimen it is assumed that the axiolite and the associated "spherulitic bubbles" were formed within the hollow spherulite before the latter was broken and thus grew in a curiously restricted environment quite different from the viscous glassy lava in which most spherulitic structures are formed.

Under these conditions it would appear that the gas generated by the dehydration which accompanied the crystallization of the felspar fibres of the axiolite was neither collected at the centre nor dissipated outside the axiolite, but proceeding outwardly along the many felspar bundles was retained as a series of bubbles, one at the outer surface of each cone. These bubbles appear to have retarded the spherulitic growth immediately beneath them but allowed growth around their sides and between adjacent bubbles. Thus each bubble became seated in its own concave emplacement.

As the axiolite grew in size the bubbles became larger and at the same time were lifted outward in their gradually enlarging cups. Finally, some (perhaps all) of the bubbles became lithified.

Occasionally micro-slides of solid spherulites from various parts of the world show instead of a regularly circular section a somewhat crenulated appearance. It may be that these crenulations mark concavities that were caused, or at least initiated, by bubbles of escaping gas remaining for some time attached to the outside of the spherulite.

It is interesting to note that Wright (17) recognized the significance of the development of bubbles external to spherulitic growths.

General Conclusions.

As a result of the foregoing studies the following conclusions appear to be justified :—

(1) The ultimate shapes taken by spherulitic growths are largely controlled by the production of gases during the process of spherulitic crystallization and by the disposal of these gases.

(2) The method of disposal of the gases is largely controlled by the viscosity and other physical properties of the enclosing lava.

(3) Where the conditions are such that no vesicles are present in the lava, spherulites without internal cavities are formed, and the gases produced are conveyed to the surface of the spherulites and dissipated in the enclosing lava.

(4) Where the conditions enable vesicles to exist spherulitic crystallization takes place around them. The gases formed under these conditions appear unable to escape into the enclosing lava and concentrate in the central vesicle where they may accumulate sufficient pressure to produce radial fractures of the spherulite followed by expansion of the cavity and supplementary spherulitic growth on the new surfaces thus formed. Hollow spherulites, pyromerides, and some compound spherulites may result from this process.

(5) Under certain very special conditions rarely attained spherulites may form in which the gases produced by crystallization accumulate as bubbles on the surface and these may subsequently solidify to form lithophysal structures.

The writer wishes to thank his colleague Dr. F. W. Whitehouse for valuable suggestions and for assistance in the preparation of the plates, and Mr. H. A. Longman, F.L.S., Director of the Queensland Museum, for the loan of specimens.

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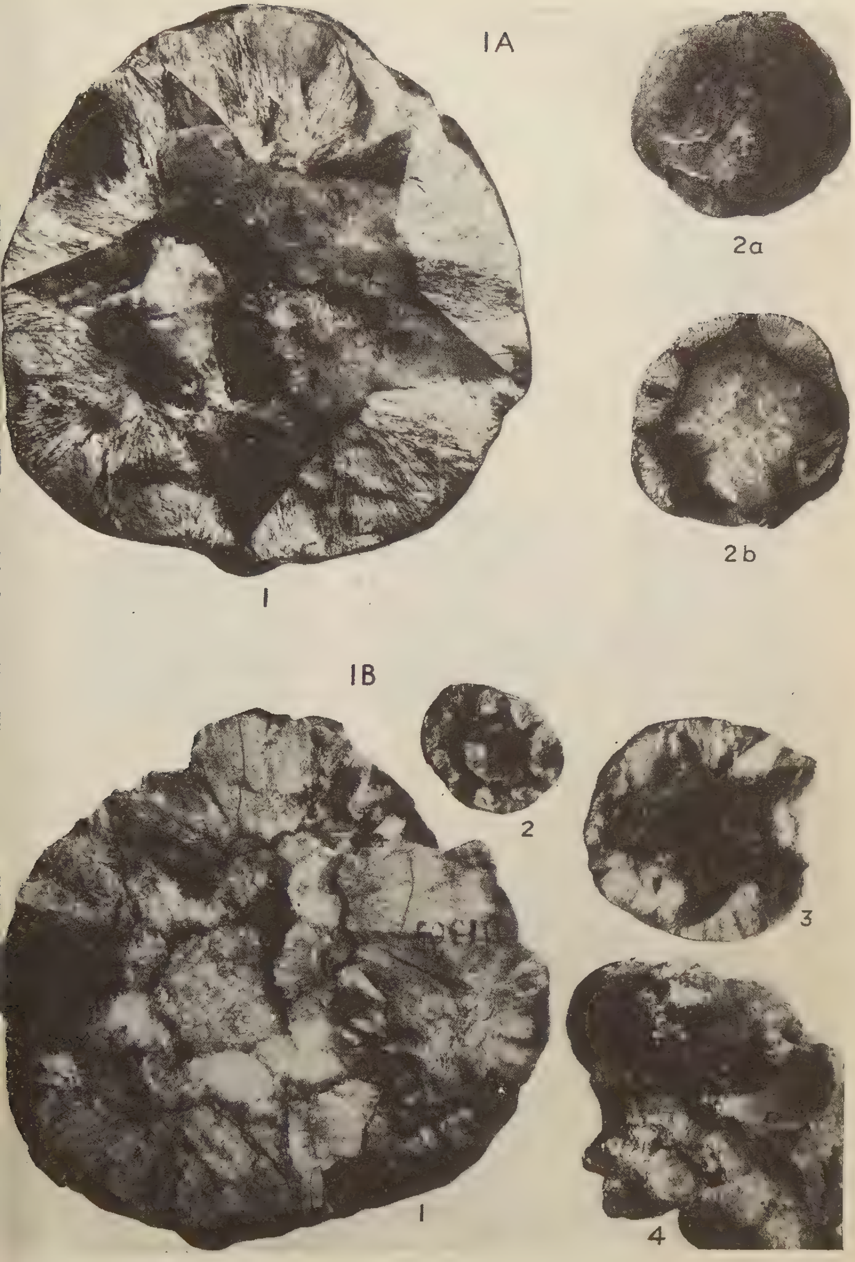
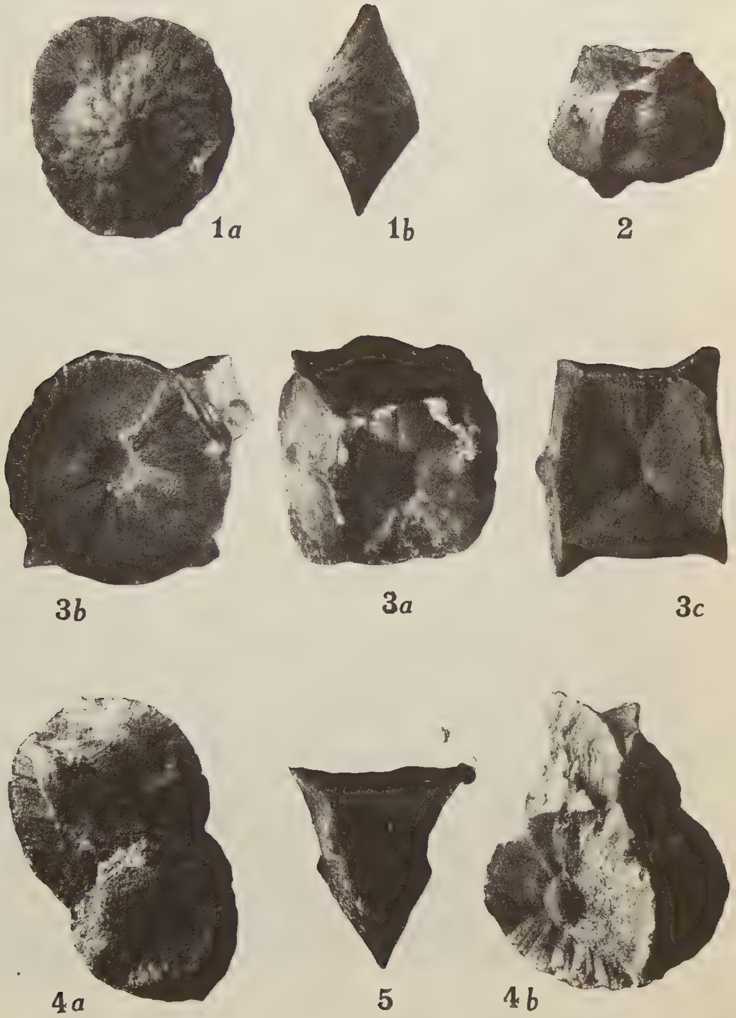


SOME SPHERULITIC GROWTHS FROM QUEENSLAND.



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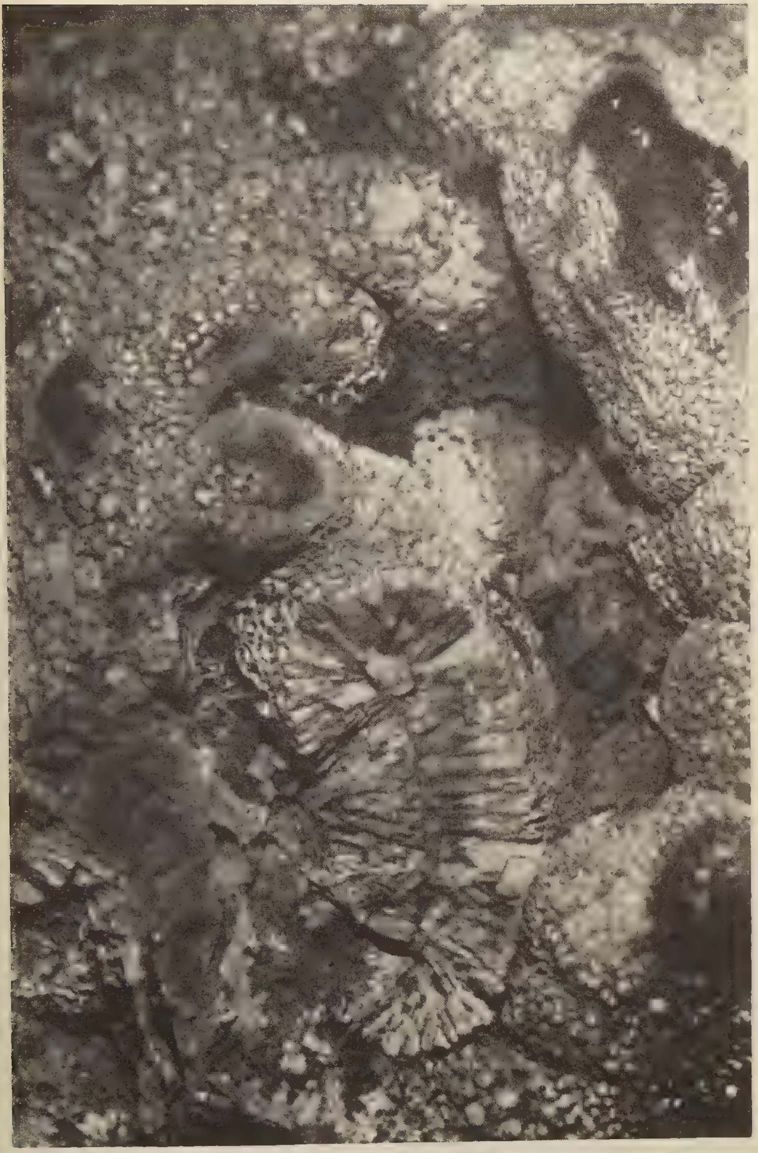

SOME SPHERULITIC GROWTHS FROM QUEENSLAND.

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(12) *Quart. Journ. Geol. Soc.*, xlviii, 1892, pl. xii, figs. 2–4.
(13) Op. cit., pl. liv (*c*), and pl. lvi (*a*).
(14) Op. cit., 257.
(15) Op. cit., 270.
(16) Ibid., 286.
(17) Ibid., 285.

DESCRIPTIONS OF PLATES VIII–IX.

PLATE VIII (1A).—NODULAR SPHERULITES FROM TAMBOURINE MOUNTAIN.

FIG. 1.—The exceptionally regular and symmetrical specimen to which special reference is made in the text. Compare with Text-figures 1 and 2. (Reduced $\frac{2}{3}$.)

FIGS. 2*a* and 2*b*.—External and sectional views of a smaller specimen. (Reduced $\frac{2}{3}$.)

PLATE VIII (1B).—NODULAR SPHERULITES FROM TAMBOURINE MOUNTAIN.

FIG. 1.—This large specimen measures 10 inches in diameter. (Reduced $\frac{3}{10}$.)

FIG. 2.—Small specimen showing somewhat irregular cavity incompletely filled. (Reduced $\frac{3}{5}$.)

FIG. 3.—Specimen showing characteristic five-pointed cavity completely filled. (Reduced $\frac{3}{5}$.)

FIG. 4.—Group of nodular spherulites, one showing internal cavity. (Reduced $\frac{3}{5}$.)

PLATE IX.—SPHERULITIC KERNELS FROM MOUNT HAY.

All natural size.

These chalcedonic casts of hollow spherulites show the following characteristics :—

1.—Regularly radiating flutings being the imprint of the innermost spherulitic growths. See especially Figs. 1*a*, 3*b*, 4*b*.

2.—Fragments of adhering portions of the original spherulitic " skins ". See Figs. 3*a*, 3*b*.

3.—Casts of the initial cavities about which the spherulites were first formed. See Figs. 3 and 4.

4.—Composite kernel due to intergrowth of two expanding spherulites. See Fig. 4.

5.—Figs. 3*a*, 3*b*, 3*c* are of especial interest owing to the close similarity of this kernel to the " square lithophysa " from Iceland, described by F. E. Wright (see text).

PLATE X.—SPHERULITIC " BUBBLES " FROM TAMBOURINE MOUNTAIN.

Axiolitic and spherulitic structures covered with numerous bubble-like lithophysae. The axiolite seen in section in the middle of the plate shows the cup-like and funnel-like depressions in which the " bubbles " are carried. (Enlarged eight diameters.)

The originals of Plate VIII (1B), Figs. 1 and 4, are in the collections of the Queensland Museum. All other figured specimens are in the Department of Geology, University of Queensland.

Quaternary Raised Beaches and the Coral Reef Problem.

By Cosmo Johns.

IN a previous communication (1)[1] it was shown that a temporary lowering of ocean-level, of the order of 1,000 metres, served not only to elucidate the nature of the British Quaternary strand line oscillations, but was also competent to explain the climatic changes that occurred during that period over a region that extended from North-West Europe to the pluviated lands south of the Mediterranean. It was also pointed out that a change in ocean-level of such magnitude must, being world-wide in extent, have recorded its effects in distant regions. There should, therefore, be a wide choice of areas where the hypothesis might be subjected to a critical and possibly decisive test.

North America, if selected, would probably serve to confirm the general applicability of the hypothesis to a similar class of events on a larger scale and complicated by the influence of the three oceans. The confirmation, if reached, would possess added value, from the climatic standpoint, in that Lake Bonneville seems to have duplicated the Quaternary history of the pluviated lands south of the Mediterranean ; but even then all that would be proved is that the hypothesis served to explain similar episodes occurring at approximately the same time in distant regions at about the same latitude. The test, even though it resulted in a general confirmation, could hardly be called decisive.

The case is rather different in the tropical part of the Pacific Ocean where hundreds of atolls and reefed islands occur in a wide belt of ocean extending about one quarter of the circumference of the earth. Here we are free from the complication of isostatic depression and recovery. Many theories have been advanced to explain the occurrence of the reefs, and the flame of controversy has, in the past, raged fiercely but contributing more heat than illumination to the problem. The strictly relevant facts are not too numerous to handle, and the problems involved are well documented. Vertical movement on an imposing scale has been suggested, but also denied ; while there still remain problems, by no means minor in character, that await solution. It is proposed, therefore, to test the ocean depression hypothesis by its application to the mode of formation and present position of coral reefs in the Pacific Ocean.

THE CORAL REEF PROBLEM.

The discussion which follows is restricted to the Coral Sea proper with its extension from 30° S. to 30° N. It forms a belt 1,200 to 2,000 miles wide and 6,000 miles long with its axis lying, nearly, parallel to the plane of the ecliptic in the Pacific Ocean. Atolls occur literally in hundreds and reef-encircled islands are numerous.

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[1] The numbers in parentheses refer to Bibliography at end of article.

Coral reefs are so well known that only a brief notice of their classification need be given here. Fringing reefs have no moat or lagoon between them and the coast. Barrier reefs possess such lagoons. Atolls are reefs encircling a lagoon with no coast land above sea-level. It is generally inferred that as, with a very few exceptions such as New Caledonia and Viti Levu in the Fiji Islands, the coral islands are composed of volcanic rocks, the foundations of the atolls must also be volcanic in origin, rising from great ocean depths with a base covering a large area.

There is a general agreement among observers that the reefs grow more rapidly on the outside where they are bathed by clean sea water, and that on a subsiding coast the reef would grow upwards while on a stationary coast it would increase in width by growing outwards.

Growth cannot take place above sea-level nor below a depth of about 40 metres. Lagoons are as a rule now being aggraded but in some instances are being excavated. This brief description includes, it is believed, all that is relevant to the present discussion.

CRITICAL DATA.

The coral reef problem is the question of the relation of land- and sea-levels before, during, and since the formation of the reefs. As a rule they are at sea-level, but some of all classes have undergone elevation varying in amount from a few metres to several hundreds. In several cases tilting has occurred. One of the most striking facts is the general, but not strict, accordance of the depths of the lagoons which are mostly 20 to 55 metres but occasionally 75 to 90 metres deep. There are also numerous drowned atolls most of which lie at depths less than 90 metres. Any explanation of the formation and present position of coral reefs that does not include these generally accordant depths of lagoons and drowned atolls is manifestly incomplete. The various theories that have been put forward will now be reviewed.

CORAL REEF THEORIES.

These have been tabulated and subjected to detailed criticism by W. M. Davis (2) in his valuable review of the coral reef problem. There will be general agreement with his conclusion that of the many theories put forward only those of Darwin and Daly merit serious attention. Darwin (3) explained the formation of the reefs by "as a rule upgrowth on intermittently subsiding foundations". He was impressed by the large number of atolls, interspersed over such a vast expanse of ocean, and questioned whether they could all be supported on mountain summits which although rising very near the surface of the sea in no one instance emerged above it.

Dana (4) followed Darwin and pointed out that the form of the reefed islands, with their embayments, strongly supported Darwin's theory. Darwin does not seem to have appreciated the importance of this support.

The many theories which followed were chiefly the work of biologists. They postulated either upgrowth or outgrowth on stationary or rising coasts. They can be studied in Davis's work, which includes what is apparently a complete bibliography. There is one, however, which must be discussed here. It is that of Daly (5), who brought his results into a final comprehensive paper. His glacial-control theory of coral reefs can be stated as growth on " still-stand foundations abraded by a lowered glacial ocean and submerged by the rise of the post glacial ocean ".

Daly concluded that the tropical ocean was chilled during the glaciation of lands in higher latitudes and coral growth inhibited except in a few sheltered bays. He attributed the lowering of the ocean to the abstraction of water to form land ice and estimated that the tropical seas had, at the time of maximum glaciation, an average level of from 60 to 70 metres lower than now. On the platforms or benches abraded by the waves of that lowered ocean the reefs would grow as the sea got warmer and rose as the water liberated from the melting ice sheets returned to it. In this way he explained the general accordance of lagoons' depths. Daly could not accept Darwin's theory of regional subsidence over such a vast area and pointed out that when examples of movement on a large scale are examined the movement is always found to be differential in character. This is as sound an argument as that of Darwin, who could not conceive as many mountain tops reaching almost up to the surface level of the sea as there were atolls.

CRITICAL STUDY BY DAVIS.

Davis visited a number of reefed islands in the Pacific including most of those that afforded critical sections for study. He extended Dana's use of land-form criteria and introduced a new element by pointing out the importance of the junction of the reef limestones with their volcanic rock foundations. " The junction would be conformable on the never-emerged and therefore non-eroded submarine slopes of a volcanic island characteristic of any still-stand theory, but any coast exposed to subaerial denudation would lose its initial form and the reef limestones when laid down must rest unconformably on their foundations."

When dealing with Daly's theory he rejected ocean chilling in the tropical ocean thus leaving the coasts protected by reefs from abrasion by the lowered sea. His most weighty criticism was to point out the general absence of cliffed spurs in the reefed islands and to demonstrate that where junctions could be examined on upraised reefs they were unconformable, thus proving subsidence to have taken place before the reef limestones were laid down. He restricted Daly's low-level abrasion to the marginal islands of the cooler sea, and thus was not able to accept his explanation of the general accordance of lagoon depths in the tropical coral sea.

The general occurrence of embayments and non-cliffed spurs was, Davis pointed out, strong evidence of subsidence and, when coupled with the proof of unconformable junctions, makes Darwin's theory nearly complete; it only requires Daly's low-level abrasion in the marginal belt islands as a supplement. Daly's theory was considered to be crippled by the failure of its chief postulate—island stability.

But Davis points out that the generally accordant depths of lagoon floors remain beyond explanation by Darwin's theory, for subsidence should, at least in some cases, have continued after an atoll was drowned. Davis explained the upraised reefs with unconformable junction by (*a*) the subsidence of the eroded coast for the reef limestones to be laid down and (*b*) uplift in recent times to their present position. A not impossible sequence of movements but, when considered with all its implications, not a completely satisfactory one. The final conclusion of Davis was that Darwin's theory of subsidence is still the best explanation.

APPLICATION OF THE 1,000 METRE OCEAN DEPRESSION HYPOTHESIS.

Here we are dealing with a movement of sea-level of much greater magnitude, and due to an entirely different cause from that postulated by Penck and Daly. It was a temporary lowering of ocean-level of the order of 1,000 metres, probably considerably more, eustatic in the strict sense of a world-wide change of level, the result of a deformation of the sea floor. The 60 to 70 metres of Daly and the 100 to 200 metres suggested by Penck (6) and attributed to the subtraction of water to form land ice was an episode superimposed on the larger movement now being discussed.

This lowering is represented by the halt in the rising sea curve (Fig. 1*c*) at the date Q. 90 of Quaternary time, after the rather rapid rise of sea-level that characterized the early stage of the Yoldia Sea submergence. Our hypothesis can now be subjected to a critical and possibly decisive test.

Darwin's woodcuts 4 and 5 (3, pp. 76–7), used to illustrate his theory of island subsidence actually represent the rising sea part of the British raised beach curve. Below woodcut 4 occurs this :—

> N.B.—" In this, and the following woodcut, the subsidence of the land could only be represented by an apparent rise in the level of the sea."

Darwin therefore clearly recognized the competence of a rise in sea-level to explain barrier reefs and atolls, but preferred and adopted as his theory, subsidence of the land. It follows therefore that a rising sea or subsiding land will explain the sea-level reefs equally well.

Darwin could not admit the possibility of there being as many islands rising from great ocean depths reaching near to, but never emerging above, sea-level as there were atolls. Daly could not conceive a vast region subsiding as evenly as required by the subsidence theory. Now both objections can retain their full weight when a rising sea is postulated, for with an original depression of 1,000 metres, or more, every island above the then sea-level, or within the 40 metres coral growth zone of the lowered ocean, would afford a possible foundation for reef building. Every island that emerged above sea-level during that time would acquire an eroded surface. Davis's explanation of the upraised reefs by subsidence and subsequent elevation is replaced by the more easily acceptable one of elevation only. Junctions must, with a rising sea as the dominant movement, be unconformable.

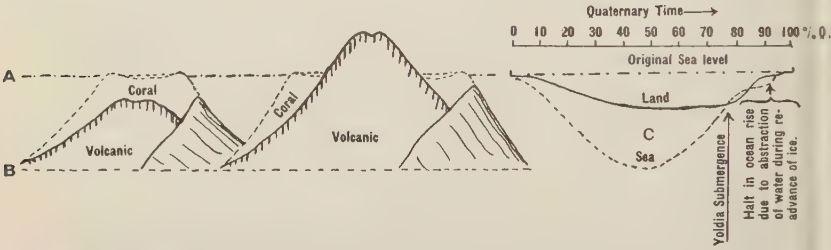
A
B
Coral
Volcanic
Coral
Volcanic
Quaternary Time
0 10 20 30 40 50 60 70 80 90 100 %.Q.
Original Sea level
Land
C
Sea
Yoldia Submergence
Halt in ocean rise due to abstraction of water during re-advance of ice.

Fig. 1.—A, Early Quaternary and Present Ocean Level. B, 1,000 metre, or more, Depression Level. C, North Atlantic Raised Beach Curve.

N.B.—It is just possible that the accelerated rate of the rise of the ocean during the Yoldia-Champlain submergence might be recognized in the profile of some of the atolls and barrier reefs. The depth at which the change of slope can be expected would be one-third of the mean thickness of the ice-field at the time of maximum glaciation, say, 500 metres or more.

Daly's glacial control theory, which suffered so severely at the hands of Davis when the general absence of cliffed spurs and the presence of embayments in the islands was demonstrated, reveals an entirely new aspect when confronted with the postulate of a first depressed and then rising ocean-level of the magnitude stated. All the objections raised by Davis can be accepted, and to this extent Daly loses the support of platforms or benches abraded by the waves of a sea lowered by 60 to 70 metres. But the halt at Q. 90 of Fig. 1c would enable fringing reefs to grow outwards and form barrier reefs, and when the rise of sea-level was resumed the reefs would grow upwards and thus enable Daly to achieve the principal object of his theory : that is an explanation of the general accordant depths of lagoons. The variations in these depths are now easy to explain ; most of the lagoon floors will have been aggraded and some excavated during the halt in the rise in sea-level. As Davis pointed out it was difficult to explain these variations on Daly's theory where the lagoon floor depths must be determined by the level of abrasion.

In a vast oceanic region, such as that under discussion, there should be no difficulty, seeing that upraised reefs are not infrequent, in assuming the submergence of some atolls. It is only necessary for this subsidence to carry the reef below the level at which coral growth occurs rapidly enough to prevent growth keeping pace with it.

A temporary Quaternary lowering of ocean-level of the order of 1,000 metres or more thus offers a more consistent explanation of the mode of formation and present position of coral reefs than any other theory. It accepts all the arguments used by Darwin, and only differs from his conclusions by adopting the very rise in sea-level which he used to illustrate his own land subsidence theory. It accepts as valid everyo ne of the weighty objections made by Davis against Daly's glacial control theory and yet succeeds in rehabilitating it, so far as its essential feature is concerned, in the coral sea from which Davis felt compelled to exclude it.

The generally accordant depths of lagoons and of drowned atolls receive a rational explanation which Davis was compelled to admit could not be given by Darwin's theory. His rather strained explanation of the upraised reefs can be replaced by a much simpler one.

It is, however, the coincidence that Darwin should actually have used an apparent rise of sea-level to illustrate his land subsidence theory that is interesting. The very magnitude of the change of sea-level that he was contemplating, as measured by the depth he gives his lagoons, is of the same order of magnitude as that of the 1,000 metres ocean depression hypothesis. There is now a temptation to consider that, as the hypothesis may be regarded as having merited the status of an established theory, it has achieved its object. But for reasons which will now be dealt with it becomes necessary to merge it as one, and only one, of the effects which resulted from the Quaternary distortion of the earth referred to in the earlier communication.

A QUATERNARY DISTORTION OF THE EARTH'S FIGURE.

A reference to Fig. 1*c* shows that at Q. 90 the halt in the rise of sea-level occurs when the ocean was about 170 metres below its present level on the scale used. This compares with Daly's 60 to 70 metres and Penck's 100 to 200 metres.

But half-way through Quaternary time the land, despite its isostatic depression, stood high enough above the prevailing sea-level to lower the snow-line and cause glaciation. At Q. 90, however, the height of the land is insufficient to have resulted in a readvance of the ice even admitting that much remained on high ground despite the invasion of low-lying land by the Yoldia Sea. A relative uplift of the land high enough above the original pre-Glacial beach-level is thus called for between Yoldia Sea time and the 25 ft. raised beach. It is also unlikely that isostatic depression alone was responsible for the land movement before Yoldia Sea time. It is only when these land movements are determined that it will be possible to see how much of Brögger's 2,600 metres is represented by movement of the sea and how much by the land. There is one feature common to the icefields on both sides of the North Atlantic and referred to by Wright (7) which might be significant. The ice-sheds, or centres of maximum glaciation, in both regions moved inwards, as glaciation proceeded, towards the ocean. The raised beach curve in its original form gave time intervals that were quantitative and a reasonably good approximation. The vertical movements must, for some time at least, remain qualitative only. The 1,000 metre, or more, ocean depression that was postulated has now become invested with a high degree of probability.

It is, however, in the Pacific Ocean that the most significant events occurred. When Darwin refused to admit the possibility of there being so many mountain summits, near to but never above sea-level, as would afford foundations for the large number of atolls, he approached closely to a question of importance not only from the coral reef standpoint but even greater in its relation to the nature of the earth's distortion. Why should there be this large number of volcanic cones interspersed over a vast but well-defined belt of ocean floor ? Their number and distribution must in some way be related to the distortion of the earth's figure which, as suggested below, resulted in the subsidence of a part, or parts, of the ocean floor. The extrusion of basaltic lava through a vast number of vents with definite and consistent alignments to build up broad-based volcanic cones on the floor of the coral sea, in time for a temporary depression of ocean-level of considerable magnitude to use them as foundations for coral reefs, are best regarded as twin effects of the subsidence of the ocean floor in the north of the Pacific.

A world-wide depression of sea-level, of the magnitude postulated, and its return to its former position means that the ocean floor in one or more places subsided. The extent of the subsidence is measured by the volume of water displaced. Suess (8), who confessed himself a heretic regarding isostasy, believed " in the formation of negative eustatic strand-lines through the sinking of ocean bottoms." Deep-seated material, of negligible strength to resist long-continued stress, would as a result flow in slowly from surrounding regions, and raise the ocean floor so that the spheroid of rotation is restored. This is simply the principle of isostasy operating on an unusually large scale. But it could hardly happen without causing far-reaching movements in both the horizontal and vertical planes in continental lands affected. The North Pacific Ocean would have its breadth decreased, while that of the North Atlantic would be increased. This is a consequence that must be faced if the eustatic movement of the sea-level postulated is accepted.

The distortion now being discussed must be regarded as the result of final yielding to long accumulating stresses. It suggests a violent interruption of the normal operation of geological processes ; something that only occurs at long intervals in the earth's history and for which we must go back as far as Permo-Carboniferous time for another example.

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Lingula Horizons in the Coal Measures of Northumberland and Durham.

By WILLIAM HOPKINS, M.Sc., Ph.D., F.G.S., The University, Durham.

INTRODUCTION.

PREVIOUS to 1858, the Northumberland and Durham Coalfield was considered to be destitute of any fauna other than the usual non-marine type. In 1858, J. W. Kirkby gave the first indication of marine fossils in this coalfield. He obtained specimens of *Lingula credneri* (Geinitz) from shales some 17 feet above the Five-Quarter seam during the sinking of a shaft at Ryhope, 3 miles south of Sunderland (9).[1] Some of these specimens are figured by T. Davidson (2).

In 1878, the late Professor Lebour obtained a few marine fossils—*Aviculopecten papyraceous*, *Aviculopecten* sp., *Orthoceras* sp., and Encrinite stems from the Gannister Series near Whittonsall, the Gannister Series being taken as including the beds between the Brockwell seam (the lowest seam widely worked) and the Millstone Grit (10).

In 1926, Mr. G. A. Burnett recorded *Lingula mytiloides* (J. Sowerby) from shales at a depth of 22 feet below the Towneley seam from the new Morrison sinking at Annfield Plain in North-West Durham (1). In 1927, Mr. J. T. Stobbs, in an appendix to Mr. M. Ford's Presidential Address to the North of England Institute of Mining Engineers, recorded a marine band from the Lower Coal Measures at a depth of 271 feet below the Brockwell seam at Washington, Co. Durham. The band contained algal-like remains and *Lingula mytiloides* (5).

Within recent years, considerable progress has been made in the zoning of the Coal Measures by the non-marine shells of the genera *Carbonicola*, *Anthracomya*, and *Naiadites* on the lines devised by

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[1] The numbers in parentheses refer to Bibliography at end of article.

Professor A. E. Trueman and Mr. J. H. Davies (3). Marine bands are known to occur in many of the British Coalfields and the correlation of some of these bands has been effected or confirmed by the determination of their horizons with reference to the non-marine shells.

I have applied the zonal scheme of Davies and Trueman to the Northumberland and Durham Coalfield (6, 7). Four zones can be definitely recognized as follows :—

(1) Zone of *Anthraconauta phillipsi*,
(2) Zone of *Carbonicola similis* and *Anthracomya pulchra*,
(3) Zone of *Anthracomya modiolaris*, and
(4) Zone of *Carbonicola ovalis*.

The Tenuis Zone is absent and if ever deposited was subsequently removed by denudation prior to the deposition of the overlying Permian rocks. The Lenisulcata Zone has not yet been recognized.

While engaged in collecting the non-marine shells I have looked for evidence of marine faunas such as are found in many of the other British coalfields. Up to the present nothing comparable to the Mansfield Marine Band of Yorkshire and Nottingham has been found, but this is no doubt due to lack of evidence. The probable associated measures are unproductive of workable coals and therefore are not accessible for examination purposes.

I have found remains of *Lingula mytiloides* at a number of horizons and, in this present note, it is proposed to record all the known horizons and occurrences of fossils in this coalfield which are not of the usual non-marine type. These horizons are shown in the accompanying figure (Fig. 1) together with the non-marine lamellibranch zones in which they occur. The table also shows the general correlation of the seams in the two counties. The highest beds of the coalfield outcropping on the north bank of the River Wear near Hylton Colliery are taken as a datum line.

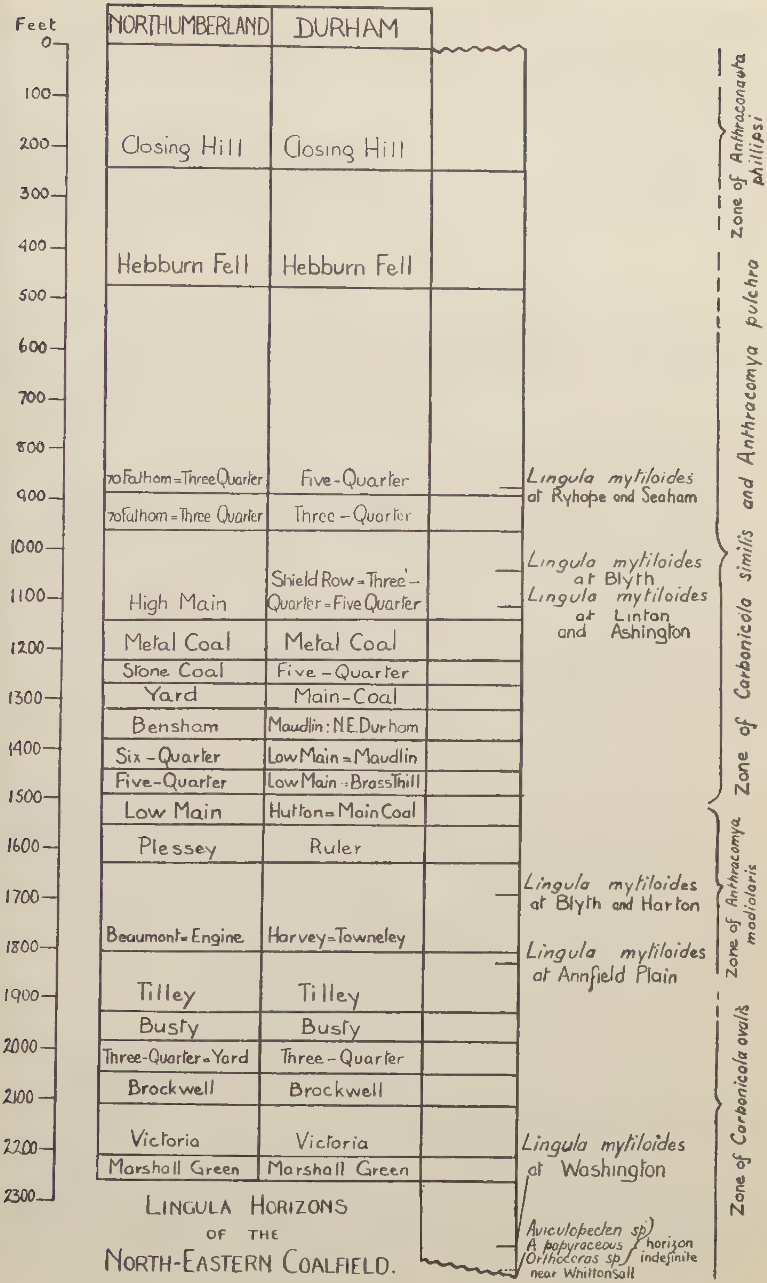
In general, only remains of *Lingula* have been found, and these are taken as representing marine or quasi-marine conditions. They sometimes occur at the bottom of a prominent mussel band, but the non-marine shells are never found in the same individual layer as the *Lingulae*, thereby indicating that the conditions of deposition were changing. The *Lingula* bands occur in the Similis-Pulchra, Modiolaris, and Ovalis Zones.

Lingula HORIZONS IN THE SIMILIS-PULCHRA ZONE.

Three horizons are known to occur in this zone.

(1) *Ryhope and Seaham Collieries.*

As previously mentioned, Kirkby discovered remains of *Lingula credneri* in shales some 17 feet above the Five-Quarter seam at Ryhope, near Sunderland. He also recorded remains of *Anthracosia*, fish, and Entomostraca from the same bed, but the *Anthracosia* forms were not found associated with the *Lingulae*. Through the


Feet
0
100
200
300
400
500
600
700
800
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1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
NORTHUMBERLAND
DURHAM
Closing Hill
Closing Hill
Hebburn Fell
Hebburn Fell
70 Fathom = Three Quarter
Five-Quarter
70 Fathom = Three Quarter
Three-Quarter
High Main
Shield Row = Three-Quarter = Five Quarter
Metal Coal
Metal Coal
Stone Coal
Five-Quarter
Yard
Main-Coal
Bensham
Maudlin: N.E. Durham
Six-Quarter
Low Main = Maudlin
Five-Quarter
Low Main = Brass Thill
Low Main
Hutton = Main Coal
Plessey
Ruler
Beaumont = Engine
Harvey = Towneley
Tilley
Tilley
Busty
Busty
Three-Quarter = Yard
Three-Quarter
Brockwell
Brockwell
Victoria
Victoria
Marshall Green
Marshall Green
LINGULA HORIZONS OF THE NORTH-EASTERN COALFIELD.
Lingula mytiloides at Ryhope and Seaham
Lingula mytiloides at Blyth
Lingula mytiloides at Linton and Ashington
Lingula mytiloides at Blyth and Harton
Lingula mytiloides at Annfield Plain
Lingula mytiloides at Washington
Aviculopecten sp
A papyraceous
Orthoceras sp
horizon indefinite
near Whittonsall
Zone of Anthraconauta phillipsi
Zone of Carbonicola similis and Anthracomya pulchra
Zone of Anthracomya modiolaris
Zone of Carbonicola ovalis

FIG. 1.

courtesy of the officers of the Geological Survey at Newcastle-on-Tyne I have been able to examine specimens of *Lingula mytiloides* collected by Mr. G. A. Burnett from a sinking completed a few years ago at Seaham, south of Sunderland. These remains from an examination of the Seaham shaft section occur above the equivalent of the Five-Quarter seam at Ryhope. At Seaham, the *Lingula* band is overlain by shales containing excellent specimens of *Carbonicola* cf. *acuta* (6). There can be no doubt that the Ryhope and Seaham occurrences represent one and the same band.

(2) *Bates's Sinking, Blyth.*

Through the courtesy of Mr. S. Bates and the Cowpen Coal Co., I have been enabled to collect and examine material tipped from a sinking now being constructed at Blyth, Northumberland. At a height of 94 ft. above the High Main seam, excellent specimens of *Lingula mytiloides* in association with a few ostracods were collected. The *Lingula* horizon is overlain by shales containing a definite suite of non-marine shells which make up five distinct bands in a thickness of 17 feet. The assemblage of the non-marine shells suggests a horizon in the lower half of the Similis-Pulchra Zone. Further, it suggests a striking similarity to the Ashclough fauna of Lancashire. Dr. W. B. Wright has found the Ashclough fauna to be particularly useful for seam correlation purposes in his area (15, 16). At Blyth, the bulk of the fauna is made up of forms resembling or closely related to *Anthracomya librata* Wright, *A. oblonga* Wright, *A. cymbula* Wright, *Carbonicola radiata* Wright, *C. actuella* Wright, *C. concinna* Wright, *C. fulva* Davies and Trueman, *C. atra* Trueman, *C. aquilina* (J. de C. Sowerby), and *Carbonicola* sp. nov. (8).

(3) *Linton Colliery and Bothal Pit, Ashington.*

Through the courtesy of Professor G. Hickling, of Armstrong College, Newcastle-on-Tyne, I have been enabled to examine specimens of *Lingula mytiloides* collected at the Linton and Ashington Bothal Collieries. At Linton, they occur in shales 5 inches above a 3 in. seam just above the High Main Seam. They are also found at the same horizon at the Bothal Pit, Ashington.

Lingula HORIZONS IN THE MODIOLARIS ZONE.

(1) *Bates's Sinking, Blyth.*

At a depth of 152 feet below the Low Main seam, i.e. the Hutton seam of Durham, I have found an excellent *Lingula mytiloides* band in dark blue shales. The band is overlain by 4 feet of barren shales followed in turn by blue shales containing a prominent mussel band. The non-marine forms present resemble or are closely related to *Carbonicola communis* Davies and Trueman, *C. aquilina* (J. de C. Sowerby), *C. oslancis* Wright, *C. carissima* Wright, *C. concinna* Wright, *C. faba* Wright, *C. obtusa* (Hind), and *Anthracomya* *williamsoni* (Brown). This assemblage suggests that the *Lingula* horizon is near the middle of the Modiolaris Zone.

(2) *Harton Colliery.*

Mr. Burnett has kindly allowed me to examine specimens of *Lingula mytiloides* from shales at a depth of 114 feet below the Hutton seam at Harton Colliery near South Shields. This horizon is near the middle of the Modiolaris Zone at Harton, and I suggest that it is the equivalent of the *Lingula* band at Blyth.

Lingula HORIZONS IN THE OVALIS ZONE.

The only known horizons are recorded by Stobbs (5) and Burnett (1) as stated previously. The *Aviculopecten* horizon recorded by Lebour (10) probably belongs to this zone.

Probable Horizon of the Equivalent of the Mansfield Marine Band.

The foregoing notes have been given to demonstrate the existence of *Lingula* bands in this coalfield and to indicate their horizons with reference to the non-marine shells. Further collecting can alone indicate whether they occur in other districts of the field. No definite band of the Mansfield type has yet been found and the question naturally arises as to whether it or any other well-known marine band occurs in Durham. Dr. E. Dix and Professor A. E. Trueman believe that a general correlation of the Cwmgorse Marine Beds and the Measures some 300 feet below in South Wales can be made with strata ranging approximately from the Mansfield to the top Marine Bed of Yorkshire on the evidence of the non-marine shells (4). Professor Trueman and his collaborators have also stressed the importance of marine bands in the upper half of the Similis-Pulchra Zone. Is there any possibility of any of these bands occurring in Durham ? At present, the only evidence suggesting any change from the usual non-marine conditions is the occurrence of *Lingula* as outlined in this note.

The Mansfield Marine Band occurs near the middle of the Similis-Pulchra Zone in Yorkshire and Nottingham. To the north of the Durham field, the equivalent Skipsey's Band has been found in Fife and also in the Sanquhar Basin of Dumfries (11). Now in Durham, there is ample evidence of the Phillipsi Zone and the succession of shells down to the Brockwell seam, which is the lowest seam widely worked, indicates quite definitely that the Similis-Pulchra, Modiolaris, and Ovalis Zones are present (6 and 7). Indeed, the general succession exhibits a similarity to that described by Dr. Wray and Professor Trueman in the Yorkshire Field (14). Unfortunately the exact boundary of the horizon separating the Phillipsi and Similis-Pulchra Zones cannot be defined as the associated measures are unproductive of workable coals and therefore inaccessible for examination purposes. The Similis-Pulchra Zone definitely includes strata as high up as the

Lingula bed at Ryhope and Seaham. The highest beds of the field occur in the Sunderland district and excellent specimens of *Anthraconauta phillipsi* (Williamson) can be collected from shales on the north bank of the Wear near Hylton Colliery, some 2 miles west of Sunderland as recorded by Stobbs (12), Trechmann, and Woolacott (13). Some 3 miles further up stream, at Offerton, I have seen another prominent *Anthraconauta phillipsi* band, but the exact horizon cannot be defined. The Hylton and Offerton exposures are the only evidence we have of the Phillipsi Zone. The Offerton occurrence is undoubtedly high up in the sequence, and higher than any possible equivalent of the Mansfield Marine Band. I suggest that the equivalent of this well-known band does exist in Durham in view of the evidence of the non-marine shells, the occurrence of the band in the Sanquhar and Yorkshire areas, and the tendency for marine or quasi-marine conditions to prevail in the Durham area at different times as indicated by the occurrence of *Lingula* at various horizons. There will be, however, only one way of demonstrating this conclusion, and this will be by the careful collecting and examining of material from a new sinking preferably in the Sunderland district should such a shaft ever be sunk. Further, this will be the only means of defining the boundary between the Phillipsi and Similis-Pulchra Zones, and at the same time of obtaining any evidence of probable marine conditions at the top of the Similis-Pulchra Zone as recognized in many other British coalfields.

ACKNOWLEDGMENTS.

In conclusion, I wish to express my sincere thanks to Mr. S. Bates of the Cowpen Coal Co. for granting me facilities to examine and collect material from the Bates's Sinking, Blyth. I am also indebted to Professor G. Hickling and Mr. G. H. Burnett for kindly allowing me to examine specimens of *Lingula* in their respective collections. To the many mining officials who have helped the investigation by providing facilities for work underground, I tender my sincere thanks.

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REVIEWS.

MINERAL DEPOSITS OF THE CANADIAN SHIELD. By E. L. BRUCE. Toronto: Macmillan, 1933. 25*s*. net.

THE remarkable development of the mining industry in Canada and especially in the Shield area during the last twenty years has opened up a new field of research to economic geology and one from which it may reasonably be expected important results will ultimately accrue. Since so many of the accounts of the various deposits are isolated in memoirs and summary reports of the Dominion and Provincial Surveys, Professor Bruce's book meets a much-felt need for a handy reference to details of the different occurrences. The descriptions are grouped by districts, the general boundaries of which are determined by geological relations, and this arrangement is satisfactory in that it recognizes the essential connection between the ore deposits and the history of the rocks in which they occur and is necessary also in view of the piecemeal nature of our knowledge of the area as a whole. Each section is prefaced by a useful summary of the general geology of the sub-province concerned, following which the individual mineral occurrences are considered in order of their economic importance, and at the conclusion a few generalizations are made regarding the genesis of the ores. A welcome feature of the book is the reproduction of maps showing the geology about the mineral occurrences, though it is unfortunate that in some cases, as on pp. 204, 205, 368, and 369, no indication is given of the significance of the various patterns employed in the diagrams. The descriptions are also supplemented by the presence of many photographs which, if they do not always help our understanding of the genesis of the ores, at least provide interesting glimpses of the *locale* of the deposits. Much less satisfactory are the camera-lucida drawings of ore and gangue, for, as is so common in this novel method of study, the subjective element plays an important part in interpreting the textural relations.

The first seven chapters deal with the processes of mineral formation. One wonders what useful end is served in giving more than 100 pages to material not within the scope of the title of the book. Certainly much of it is beyond the interest of the casual reader, while, on the other hand, it is to be hoped that serious students of the subject will approach the study with a somewhat fuller knowledge of geology and petrology and with a deeper appreciation of the principles of physical chemistry than is assumed in these pages. The theoretical aspects of igneous petrology are mentioned while the subject of thermal metamorphism, certainly as pertinent, is ignored, and this first part suggests a fission between the study of mineral deposits and the general science of petrology which, if it exists, is most regrettable. It provides no *open sesame* to the understanding of the processes of mineral formation which form a part of the study of petrogenesis, and its purely formal character is shown by the fact that in the sequel none of the principles mentioned are expanded and made concrete in the deposits described.

One naturally turns to the section dealing with the Sudbury nickel ores to see what new light is shed on these much discussed mineral occurrences, and it is interesting to find that the older view of direct gravitational differentiation of the sulphides from the " norite " is set aside in favour of the hypothesis of their injection as a melt, at a late stage, near the basal margin of the Sudbury sheet. Little attention is paid to the presence of the ore in the younger granite, and it is to be regretted that though many cross-sections are given of the ore-bodies, the most illuminating of all, that of the Creighton mine, published by the International Nickel Company, is not included. The Killarnean age of this granite has been confirmed by the Dominion Geological Survey as shown by their most recent map of the general area, and the difficulties which the presence of the ore within this intrusion presents to the theory favoured is not removed by the extravagant suggestion that the intrusive contacts of the granite are really due to its having been melted by the " norite ". This hypothesis is one which might well be discussed in the light of the theories of igneous petrology mentioned in the first part of the book.

Despite these criticisms, however, the book is a distinct contribution to the economic geology of Canada, since it brings together within geological provinces the very varied ores of the region, and is thus a first step towards their systematic study.

T. C. PHEMISTER.

LEHRBUCH DER ANGEWANDTEN GEOPHYSIK. By HANS HAALCK. pp. vii + 376, with 142 text-figures and 6 plates. Berlin: Borntraeger, 1934. Price, geheftet 24 RM., gebunden 26 RM.

MANY years ago the powers that control the GEOLOGICAL MAGAZINE decided that the technical side of geophysical methods lay outside its province, while fully recognizing their great importance for the development of the science of geology along modern lines. Therefore it must suffice merely to draw attention to the publication of this book, which, as stated in the preface, is intended to supply the want of a general comprehensive account of recent methods. It may perhaps be doubted whether this want is as deeply felt in the English-reading world as the author seems to think it is in Germany. The English literature seems to be fairly considerable in bulk.

REPORTS AND PROCEEDINGS.

MINERALOGICAL SOCIETY.

15th March.

Mr. Arthur Russell: Baryte crystals from the Manvers Main Colliery, Wath-upon-Dearne, near Rotherham, Yorkshire. A cavity containing exceedingly beautiful colourless crystals of baryte was discovered in the roof of the Parkgate Seam of this colliery in 1930, and the occurrence was briefly described by Mr. C. P. Finn in the same year. Two distinct habits of crystals occurred, prismatic and tabular. The crystals are attached to small coloured rhombohedra of dolomite, which form a coating on the grey sandstone, both baryte and dolomite being for the most part more or less thickly sprinkled with small, bright, twinned crystals of chalcopyrite. The crystal forms present are listed and drawings of the crystals are given.

Dr. W. Q. Kennedy: The conditions for the crystallization of hornblende in igneous rocks. By means of a statistical study of the MgO-CaO-FeO ratios of igneous hornblendes it is shown that the latter occupy an intermediate position between the diopsidic pyroxenes and the magnesia-rich, lime-poor monoclinic and orthorhombic pyroxenes. It is concluded, therefore, that (1) pressure and the concentration of the volatile constituents are not the sole determining factors in the crystallization of pyroxene and hornblende from a magma, but that the original proportions of the constituent oxides play an equally important part; (2) a magma which, under physical conditions tending towards the retention of the volatile constituents, will produce hornblende as its ferromagnesian constituent will, under effusive conditions, produce diopsidic pyroxene plus hypersthene or enstatite-augite. Thus hornblende = diopsidic pyroxene + orthorhombic pyroxene or enstatite-augite (pigeonite).

Mr. Arthur Russell: An account of British mineral collectors and dealers in the seventeenth, eighteenth, and nineteenth centuries (continued). John Williams, of Scorrier House, Cornwall, mine agent and adventurer, copper and tin smelter and banker, born 23rd September, 1753, died 17th April, 1841. The collection of Cornish minerals which he had formed at Scorrier in conjunction with his son John, born 3rd August, 1777, died 11th August, 1849, was greatly added to by the latter. The collection, which contained about 10,000 specimens, was one of the three finest in Cornwall. In 1893 Mr. John Charles Williams disposed of the collection by presentation between the British Museum, The Royal Institution of Cornwall, Truro Museum, and the Robert Hunt Memorial Museum, Redruth. In addition to a memoir of both the Williams, a general account of the collection and its outstanding specimens is given.

M. H. Hey: On the advantages of the face-adjustment for two-circle goniometry. The statement often made that an accurate projection cannot be so quickly prepared from two-circle measurements made with the face-adjustment as from measurements made with the zone-adjustment is shown to be incorrect, and a construction for the preparation of a projection is described. The face-adjustment has several decided advantages over the zone-adjustment.

The following papers were taken as read:—

M. H. Hey: An improved method of crystallographic computations. A system for the computation of the elements of a crystal from two-circle goniometric measurements is described in which due weight is given to each measured angle in accordance with its estimated probable accuracy.

M. H. Hey: On face- and zone-symbols referred to hexagonal axes: a correction. The system of four-index hexagonal zone-symbols described by L. Weber is correct, and that formerly described by the author is abandoned. The derivation of Weber's symbols from a gnomonic or linear projection is described, and their relation to the "three-index" symbols noted.